Research on Logistics Distribution in E-commerce Environment Based on Particle Swarm Optimization Algorithm

Zou Yufeng, Wan Si*
Shanghai Sipo Polytechnic, Shanghai, 201399, China

*Corresponding author: 373756262@qq.com

Abstract. In order to improve the efficiency of logistics distribution under electronic commerce environment and reduce the logistics cost of distribution path length and time delay, to solve the problem of logistics distribution method at present larger and better convergence, a logistics distribution method in e-commerce environment is proposed based on particle swarm optimization algorithm, the characteristics of construction behavior the characteristics of logistics distribution under the e-commerce environment, the logistics distribution problem into a multi-objective optimization problem of particle swarm optimization. Based on the IOT technology, to establish a stable and efficient logistics supply chain structure, according to the interval distribution characteristics of e-commerce products to the distribution of the time interval of extraction group behavior of particles, the adaptive path characterized the amount of logistics distribution optimization and implementation under the environment of e-commerce logistics distribution path optimization, improve the coverage level of logistics and distribution of the simulation nodes. The results show that the method has stronger spatial search ability, it has higher convergence accuracy and faster search speed, and reduces the time cost and path overhead of logistics delivery.

Keywords: particle swarm optimization, e-commerce, logistics distribution, convergence, path optimization

1. Introduction
With the rapid development of electronic commerce and logistics technology, logistics technology development, large-scale logistics intelligent and network and constantly improve the level of logistics distribution into the big data information processing and intelligent network management era, carries on the flow under the environment of e-commerce route optimization design, improve the efficiency of logistics distribution logistics supply. Chain information management and integration, is the logistics supply related information technology through network, into the entire logistics operation cycle, along with the development of the Internet of things, making the logistics supply chain information network model construction to become a reality, under the environment of e-commerce, based on Internet of things technology, establish a stable and efficient logistics supply chain the promotion of logistics supply chain oriented specialization and the direction of social development,
and promote industrial innovation, reduce costs, promote the whole production industry. With the continuous development of the logistics industry. However, more nodes logistics supply chain network structure oriented, in the topology of the entire network, including supply, distribution, procurement entities such as nodes, including highway, railway, waterway, aviation, pipeline connection line edge model, resulting in logistics distribution are diversified, in order to improve the efficiency of logistics distribution, optimization design of logistics distribution of e-commerce environment, and promote the further development of electronic commerce.

The optimization of logistics distribution using Internet technology and Internet of things technology for logistics distribution information processing and data analysis, realize the logistics information integration and scheduling in intelligent information processing platform integration, it can improve the efficiency and accuracy of the logistics distribution. The transmission and processing of logistics distribution information through RFID, barcode recognition, Bluetooth technology identification label collection and distribution process to match the need in the logistics distribution information accurately in the information processing platform of transmission and intelligent scheduling of large logistics, through information monitoring and data mining, improve the management level of intelligent logistics distribution, design method of intelligent transmission system of logistics distribution information, in the optimization of large scale intelligent logistics the information processing platform is of fundamental significance to improve the logistics service level. The information collection, processing and distribution. Based on the information network management, logistics information identification through wireless RFID technology, data distribution information of the perception layer construction, based on the SIP protocol, RTP protocol to establish logistics information transmission network protocol, combined with the corresponding data mining and information scheduling method of information transmission system, according to the design principle, the related the scholars have carried on the system design, research achievements, some of which, in reference literature [4] presented a number of Logistics Intelligent Recognition Technology Based on computer vision image, computer vision, image acquisition and recognition method for logistics label acquisition and classification of the logistics intelligent information transmission design in the complex network environment, improve the active tracking and positioning information of logistics distribution information, but the method is accuracy limit visual acquisition of large system, the reliability is not good. In reference literature [5], a design method of modern logistics and scheduling system is proposed based on cloud computing, using wireless sensor networks and cloud computing technology for logistics information processing and transmission, intelligent and high integration system, but with the increase of the size of the distribution information system, the robustness is not high.

Aiming at the above problems, this paper proposes a method of electronic commerce logistics and distribution of the particle swarm optimization algorithm based on particle swarm optimization, the characteristics of construction behavior of logistics distribution under the e-commerce environment, the logistics distribution problem into a multi-objective optimization problem of particle swarm optimization, the adaptive path of logistics distribution optimization realization, under the environment of e-commerce logistics distribution path optimization, improve the level of coverage of logistics distribution. Finally, the simulation test is carried out, showing the superiority of this algorithm.

2. Overall framework of logistics distribution optimization design
Three layers structure design of the logistics distribution information transmission system is designed in this paper, respectively for the logistics distribution information of original data in the perception layer, network layer network protocol and middleware configuration, application layer for logistics application and software development, as shown in Figure 1.
Among them, the data acquisition using RFID electronic label recognition technology for logistics information data in the perception layer, including the physical distribution information of the logistics and distribution of target user information, logistics information including object size, weight, size and variety, the user information including the delivery address, the information of the customer. The logistics distribution information collection the handheld device design of Android platform based on Open Web Core as the core, the logistics distribution information read by UHF RFID reader, tag data interpretation and application software, the handheld device by transmitting radio waves to the electronic tag, via Bluetooth or infrared technology to read the object bar code, intelligent physical information in writing. In the network layer, intelligent routing mechanism in the construction of logistics distribution information in the TinyOS operating system, network transmission network protocol design, by using multiple components (component) connection middleware technology for network transmission control, improve the transmission capability of intelligent logistics information, the output of the application layer, to connect the various components and modules through the data transmission interface, import logistics information, the establishment of logistics distribution information database, calculating the integrated operational logistics information environment under the cloud, to achieve a certain logic function module through the application software development. According to the design principle, architecture and software development and design of logistics information intelligent transmission system. Using OpenStack networking platform to build logistics information network architecture provided for distribution network design, information transmission, optimization of logistics distribution under electronic commerce environment by using particle swarm optimization algorithm.

3. Model construction and problem description of logistics distribution constraint parameter in e-commerce environment

3.1 Constraint parameter model of logistics and distribution network

Supply chain logistics network, the supply, distribution, procurement and warehouse entity, dock, station, highway intersection is abstracted into the nodes of the network, the railway, highway, waterway, pipeline transportation line abstract network edge network system model on the number of logistics and transport logistics transportation capacity as the network load, the maximum load of nodes and edges of the logistics supply chain network model can withstand the node and the network topology in the edge capacity. The logistics supply chain network in normal operation, the total load is expressed as:

\[ l(v_i) = l(av) + l(cv) + l(bv) \]  \( (1) \)

The load capacity of adjacent nodes \( v_a, v_b \) and \( v_c \) in the logistics supply chain network model is expressed as:

\[ l(v_a) = l(ba) + l(ca) \]  \( (2) \)

\[ l(v_b) = l(ab) + l(cb) \]  \( (3) \)

\[ l(v_c) = l(ac) + l(bc) \]  \( (4) \)

In the logistics supply chain network, the initial time generates a random failure of joints, in the next time period have different failure types of logistics capacity overload, logistics supply chain network invulnerability model is obtained by the analysis on the festival said:

\[ l_{\text{prev}} = l_v + l_{\text{add}} = l_v + \frac{l(v_i)}{d_i} \]  \( (5) \)
In the formula, $l^{\text{over}}$ is the overload of logistics supply chain network side current load, $l^{\text{el}}$ is the logistics supply chain network overload side of the original load, $\text{addl}$ is the logistics supply chain network load value added, according to the different degree of $l^{\text{over}}$ overload, the logistics supply chain overload edges in the network is divided into several types of structure, using $E = (E_1, E_2, ..., E_i, E_n)$ to indicate SFG dimensional overload the entire logistics supply chain according to the matrix side:

$$e = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1m} \\
 e_{21} & e_{22} & \cdots & e_{2m} \\
 \vdots & \vdots & \ddots & \vdots \\
 e_{m1} & e_{m2} & \cdots & e_{mm} \end{bmatrix}$$

(6)

Thus, the probability density function of the overload edge of the offspring of the supply chain network system is obtained after the random generation of an overload side. In the matrix, $e_{ij}$ ($e_{ij} \geq 0$) is the overload edge of a side $E_i$ type which is randomly obtained in the supply chain network.

### 3.2 Objective function construction of logistics distribution optimization

By using the particle swarm optimization algorithm, construct the behavior characteristic of logistics distribution under the e-commerce environment, the logistics distribution problem into a multi-objective optimization problem of particle swarm optimization, multi-objective optimization problem requires simultaneous optimization of multiple objective function, the objective function is called objective function vector. The mathematical distribution of multi-objective optimization problem described as follows:

$$\min F(x) = [f_1(x), f_2(x), ..., f_n(x)]$$

$$s.t. g_i(x) \leq 0 \text{ (or } = 0) i = 1, 2, ..., n$$

$$h_j(x) = 0 j = 1, 2, ..., m$$

(7)

Among them, $f_i(x)$ ($i = 1, 2, ..., n$) is the objective function of distribution path distribution, $h_j(x)$ is inequality constraint, and $g_i(x)$ is equality constraint. Here, several important concepts in multi-objective optimization are introduced:

**Definition 1:** Pareto optimal solutions for feasible solutions of $X^* \in S$, if and only if there is not another feasible solution of $X \in S$, so that all $f_i(X^*) \leq f_i(X)$ inequality was established, in which $i = 1, 2, ..., n$, and at least one $i$, the strict inequality established by $f_i(X^*) < f_i(X)$, is called a Pareto $X^*$ is an optimal solutions of multi-objective optimization problem.

**Definition 2:** Pareto Frontier: the set of all Pareto optimal solutions becomes the Pareto frontier.

Suppose that the PSO algorithm searches in the D dimension space and consists of $m$ particles constituting a population, then the current position of the $i$ particle can be expressed as the vector $x_i = (x_{i1}, x_{i2}, ..., x_{iD})$, and its speed can be denoted as vector $v_i = (v_{i1}, v_{i2}, ..., v_{iD})$ and the optimal location of the search is $p_i = (p_{i1}, p_{i2}, ..., p_{iD})$, the global optimum position of the whole particle swarm is $p_g = (p_{g1}, p_{g2}, ..., p_{gD})$, where $i = 1, 2, ..., m$. Particle update formula is as follows:

$$v_i^{t+1} = \omega v_i^t + c_1 r_1 (p_{id} - x_i^t) + c_2 r_2 (p_{gd} - x_i^t)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

(8)

Wherein, $t$ is the number of iterations for omega; inertia weight; $c_1, c_2$ are learning factors, $r_1$, $r_2$ are random number distribution between $[0,1]$, and $c_1$, $r_1$ combined with control particle impact factors, $c_2$ and $r_2$ combined with restriction factors. The particle population particle swarm search termination condition set the maximum number of iterations is reached the preset algorithm or meet the accuracy requirements.
4. Realization of logistics distribution optimization algorithm

4.1 Particle swarm optimization algorithm

Based on the Internet of things technology, a stable and efficient topology structure of logistics supply chain is established. In this paper, the network structure of logistics supply chain is represented by the \( G = (V, E) \) model of multi-weighted connected three-tier structure, \( \{V\} = n, \{E\} = m, V = \{v_1, v_2, \ldots, v_n\} \) is the nodes of supply chain logistics network topology with \( E = \{e_1, e_2, \ldots, e_m\} \) as a set of supply chain network structure of edges. In the topology, according to the interval distribution characteristics of e-commerce products to the distribution of the time interval from the particle swarm behavior, logistics distribution path optimization, optimization of e-commerce logistics distribution path weighted factor this definition random inertia weight, inertia weight is one of the most important parameters of PSO algorithm, the influence of history on the current state of the control. In order to make the global and local search capability of the algorithm to achieve the balance could be achieved by adjusting the inertia weight. The improved PSO algorithm in most of the commonly used linear decreasing inertia weight strategy. The initial inertia weight can get greater value to the global search algorithm, but the large overhead and low searching efficiency in the late stage; The algorithm can accelerate the convergence of the algorithm, but the algorithm is easy to fall into the local optimum and lacks the ability to improve the solution.

The inertia weight is set as a distribution of random numbers, using the characteristics of inertia weight adjustment of random variables, the algorithm can quickly jump out of the local optimum is conducive to maintain the population diversity and improve the algorithm's global search performance, because of the randomness that can have the opportunity to take both the particle weight larger or smaller value in the early operation again, to get smaller or larger weights in the calculation of the period. In the near optimal particle, the random distribution of inertia weight can produce relatively small value, this is conducive to speed up the convergence speed of the algorithm; if the random inertia weight is used in large value will be calculated by a large value of fitness function. The value than the optimal value, the larger inertia weight will be eliminated, the algorithm will re produce inertia weight of new value. If the particle is far from optimal particle distance, random inertia Weight has a greater value, such as to speed up the convergence speed of the algorithm. If the random inertia weight value is small, then the adaptation will be worse than the optimal value function, the smaller the inertia weight will be eliminated, the inertia weight value of algorithm will be re produced. Using a linear decreasing strategy. If the appropriate value of inertia weight was not found in the early stage, the algorithm will be more difficult to converge to the best point. The weight value by using the method of random distribution, the inertia weight can get better value in the later period, the algorithm is not easy to adapt to the stagnation function value. Based on the above analysis, the random inertia value \( \omega \) generating formula is as follows:

\[
\omega = \mu_{\min} + (\mu_{\max} - \mu_{\min}).\text{rand}(\ ) + \sigma.\text{randn}(\ ) \tag{9}
\]

Among them, \( \mu_{\min} \) is the minimum value of stochastic inertia weight, \( \mu_{\max} \) is the maximum value of random inertia weight; \( \text{rand}(\ ) \) is uniformly distributed random number \([0,1]\); third \( \text{randn}(\ ) \) is the normal distribution of the random number, \( \sigma \) (variance) is used to measure the random variable weights omega and the mathematical expectation (mean) the degree of deviation between, is to control the weight error value, which makes the weight \( \omega \) is evolution to the desired weight direction, do so is on the basis of the experimental error normally obey the normal distribution.

The inertia weight of the adaptive path of logistics distribution optimization design, particle swarm optimization algorithm, the particle more to their optimal learning and less to social optimum learning, to strengthen the global search ability of particle; and in the late stage of C1 is small and large values of C2 search, make the particles more to study the social optimum and less to its optimal learning, is conducive to rapid convergence to the global optimal solution. Therefore, the following changes of learning factor formula:
Among them, $c_{1\text{ini}}$, $c_{2\text{ini}}$ respectively represent the initial learning factor $C_1$, $C_2$, and $c_1$, $c_2$ respectively represent learning factor $c_1$, $c_2$ iterative final value, $T$ represents the current number of iterations, $T_{\text{max}}$ represents the maximum number of iterations.

4.2 Optimization of logistics distribution path in e-commerce environment

The use of particle swarm optimization algorithm for distribution path optimization, implementation under the environment of e-commerce logistics distribution path optimization, improve the coverage level of logistics and distribution, in order to prevent the external repository of particles fall into local optimum, this paper proposes a hop improvement mechanism, this mechanism has two directions: one is the internal operation mechanism of hops to improve the search depth of the search area is known; two is to improve the search ability of unknown regions outside the hop mechanism, as shown in Figure 2. The introduction of the mechanism, to provide effective information to find more non-dominated solutions for particle external repository, to obtain the population diversity. Disadvantage of this mechanism is only applicable to external storage in the library of particles.

$$\begin{align*}
V_{ij}(g+1) &= V_{ij}(g) + c_1 r_{ij}(g) [P_{best_{ij}}(g) - x_{ij}(g)] \\
&+ c_2 r_{2ij}(g) [G_{best_{ij}}(g) - x_{ij}(g)];
\end{align*}$$

\[ (14) \]

Wherein, $\alpha$, $\beta$ are the free vectors in the external repositories of known search regions, and two new search vectors of unknown search region $O_\alpha$ and $O_\beta$ can be obtained by the following formula:

$$\begin{align*}
O_\alpha &= \alpha + a(\alpha - \beta) \\
O_\beta &= \beta + b(\beta - \alpha) \\
0 < a, b < 1
\end{align*}$$

\[ (11) \]

It can be concluded that the time spent in each component of the logistics dispatch processor $p_i$ in the e-commerce environment is:

$$\begin{align*}
x(t) &= [x_{-p_{i-1}}(t), x_{-p_i}(t), \ldots, x_p(t)]^{T}_{N+1} \\
s(t) &= [s_1(t), s_2(t), \ldots, s_N(t)]^{T}_{N+1}
\end{align*}$$

\[ (12) \]
\[ (13) \]

Wherein, $x_p(t)$ is the transpose space, $N$ is the number of delivery tasks, and $s_1(t)$ is the information characteristics of a single delivery task.

In conclusion, the optimization steps of logistics distribution based on particle swarm evolution are as follows:

Step1: Initialize the particle swarm, the initial position as the best position of each individual history $P_{best}$, the current best position of each particle $P_{best}$ is determined by the following formula:

$$\begin{align*}
\begin{cases}
V_{ij}(g+1) &= V_{ij}(g) + c_1 r_{ij}(g) [P_{best_{ij}}(g) - x_{ij}(g)] \\
&+ c_2 r_{2ij}(g) [G_{best_{ij}}(g) - x_{ij}(g)];
\end{cases}
\end{align*}$$

\[ (14) \]

Step2: Updating the spatial location of each particle in a particle swarm.

$$\begin{align*}
G_{best_{ij}}(g+1) &= \arg \min_{P_{best_{ij}}} f(P_{best_{ij}}(g+1))
\end{align*}$$

\[ (15) \]

In order to balance the global search and local search, Shi and Y. propose the inertia weight $w_i$, so there are some:
\[ V_g^{(g+1)} = wV_g^{(g)} + c_1 r_{1g}^{(g)} [P_{best_g}^{(g)} - x_g^{(g)}] + c_2 r_{2g}^{(g)} [G_{best_g}^{(g)} - x_g^{(g)}], 0 \leq w \leq 1; \] (16)

Step3: update the external repository by jumping improvement mechanism compares the non inferior updated non dominated solution and the external repository solution of the particle swarm, to determine the non inferior solution of the particle swarm is stored into the external archive, and calculate the Euclidean distance;

Step4: updates the local optimum position of particles and determines archive particles;

Step5: If the satisfies the termination condition, the operation is stopped, otherwise, transferred Step2.

5. Simulation and result analysis

In order to test the algorithm performance in the realization of logistics under e-commerce environment distribution limitation and path optimization in the simulation experiment. The simulation experiment based on Matlab 7 software, the computer model Dell 2210b, the population size of particle swarm \( m = 40 \), dimensions \( D = 30 \), maximum iterations are 300, In SSPSO, learning factor \( C_1, C_2 \) are 2, inertia weight \( \omega = 0.9 \), other parameters are set as: \( \omega_{\text{max}} = 0.9, \omega_{\text{min}} = 0.4, c_{1\text{ini}} = 2, c_{1\text{fin}} = 0.5, c_{2\text{ini}} = 0.5, c_{2\text{fin}} = 2, \mu_{\text{max}} = 0.95, \mu_{\text{min}} = 0.5 \), performance metrics are described as follows:

(1) Convergence measure (GD), GD can be obtained non dominated solutions to Euclidean distance I set of reference points is calculated, its form is as follows:

\[ GD = \sqrt{\frac{1}{n} \sum_{i=1}^{n} d_i^2} \] (17)

When \( GD = 0 \), it is shown that all the non inferior solutions are on the ideal Pareto front, the better the convergence of the algorithm is.

(2) Distribution measure. Deb et al. Proposed distribution measurement (diversity measure DM), the characteristics of the measurement is simple, no matter whether the algorithm converges to the ideal Pareto frontier, timeliness evaluation can be carried out on the logistics distribution scope of non inferior solution, formula I are as follows:

\[ DM = \frac{d_e + d_b + \sum_{i=1}^{n-1} d_i - \sum_{i=1}^{n-1} d_i}{n-1} \] (18)

\[ d_e + d_b + (n-1) \sum_{i=1}^{n-1} d_i \]

Among them, \( d_e \) is the distance from the extreme point to the non inferior solution, \( d_b \) is the distance from the boundary point to the non inferior solution, and the larger the. In the ideal case, the non inferior solutions are all on the Pareto front.

(3) Uniform measurement of distribution. In the evaluation of logistics distribution solution set distribution uniformity, I use the Pareto distance metric (spacing, SP).SP is proposed by Schott to evaluate the Pareto solutions of uniform distribution and not in the ideal Pareto front, the calculation formula is as follows:

\[ SP = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (d_i - \frac{\sum_{i=1}^{n-1} d_i}{n-1})^2} \] (19)

Taking the above indexes as the reference factors of performance comparison, the logistics distribution simulation analysis is carried out, and the comparison results of the above test indexes are obtained by using different algorithms, as shown in Figure 3~5.
Comparison of convergence curves for SP

Comparison of convergence curves for GD

Comparison of convergence curves for DM

Figure 3 Test results of uniform distribution of logistics distribution

Figure 4 Logistics distribution path convergence comparison results

Figure 5 Test results of distribution measurement of logistics distribution
The results of the test were analyzed statistically, and the statistical results were shown in table 1.

Table 1 Statistical Analysis of performance testing

| Performance metric parameters | Proposed algorithm | IMOPSO          | NSGA2          |
|------------------------------|--------------------|-----------------|----------------|
| GD                           | 8.545e-007         | 1.656e-006      | 8.065e-005     |
| SP                           | 1.654e-005         | 3.565e-004      | 5.654e-003     |
| DM                           | 8.365e-004         | 1.675e-004      | 6.565e-006     |

The above analysis results show that the convergence speed of this algorithm is faster than the other two algorithms, the algorithm to optimize the results of variance than other algorithms, so its better robustness, higher convergence precision, faster search speed. In addition, measurement is also higher than the other two algorithms can be distributed and timeliness of logistics path coverage from the result of, and see that this algorithm shows higher convergence precision and faster search speed, reduce the time cost and path cost of logistics distribution, its optimization performance was significantly higher than that of other algorithms.

6. Conclusions
This paper studies the optimization problem of logistics distribution under electronic commerce environment, in order to reduce the cost of logistics distribution path length and time, this paper presents a method of electronic commerce logistics and distribution of the particle swarm optimization algorithm based on particle swarm optimization, the characteristics of construction behavior of logistics distribution under the e-commerce environment, the logistics distribution problem into a multi-objective optimization problem of particle swarm optimization. Based on the IOT technology, to establish a stable and efficient logistics supply chain structure, according to the interval distribution characteristics of e-commerce products to the distribution of the time interval from the particle swarm behavior, the adaptive path characterized the amount of logistics distribution optimization and implementation under the environment of e-commerce logistics distribution path optimization, improve the level of coverage of logistics distribution. It is concluded that the use of the proposed method for electronic commerce Logistics distribution, logistics distribution uniformity, convergence performance and space searching ability, better performance, has higher convergence precision and faster search speed, reduce the time cost and path cost of logistics and distribution, logistics and distribution in the search path has good application value in the optimization.

References
[1] JIA An-chao, ZHOU Gang. Study on Selection of Suppliers Based on Rough Set and BP Neural Network [J]. Logistics Technology. 2012.31 (12): 229-232.
[2] BI Anqi, WANG Shitong. Transfer Affinity Propagation Clustering Algorithm Based on Kullback-Leiber Distance [J]. JEIT, 2016, 38(8): 2076-2084.
[3] LONG M, WANG J, DING G, et al. Adaptation regularization: A general framework for transfer learning [J]. IEEE Transactions on Knowledge and Data Engineering, 2014, 26(5): 1076-1089.
[4] PATRICIA N and CAPUTO B. Learning to learn, from transfer learning to domain adaptation: A unifying perspective[C]. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, Columbus, OH, USA, 2014: 1442-1449.
[5] SUN L and GUO C H. Incremental affinity propagation clustering based on message passing[J]. IEEE Transactions on Knowledge and Data Engineering, 2014, 26(11): 2731-2744.
[6] MORADI M, KEYVANPOUR M R. An analytical review of XML association rules mining [J]. Artificial Intelligence Review, 2015, 43(2):277-300.
[7] DONG G L, RYU K S, BASHIR M, et al. Discovering medical knowledge using association rule mining in young adults with acute myocardial infarction[J]. Journal of Medical Systems, 2013, 37(2):1-10.
[8] KHALILI A, SAMI A. SysDetect-a systematic approach to critical state determination for industrial intrusion detection systems using Apriori algorithm[J]. Journal of Process Control, 2015,
2776:154-160.
[9] KESHAVAMURTHY B N, KHAN A M, TOSHNIWAL D. Privacy preserving association rule mining over distributed databases using genetic algorithm [J]. Neural Computing & Applications, 2013, 22(Supplement 1):351-364.
[10] CZIBULA G, MARIAN Z, CZIBULA I G. Detecting software design defects using relational association rule mining[J]. Knowledge and Information Systems, 2015, 42(3):545-577.
[11] HILLS J, BAGNALL A, IGLESIA B D L, et al. BruteSuppres-sion:a size reduction method for Apriori rule sets[J]. Journal of Intelligent Information Systems, 2013, 40(3):431-454.