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An analysis of location optimization of science and technology with the perspective of logistics network based on chaotic particle swarm algorithm

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ABSTRACT

Technical industry and large-scale scientific instruments play the role of promoting economic and social development. But the existing studies mostly focus on the operational efficiency of large-scale scientific instruments and technical industry, and rarely on the spatial resources allocation of large-scale scientific instruments, that is, spatial layout. In this article, the location optimization of the science and technology resources for operation were analyzed using chaotic particle swarm optimization (C-PSO) algorithm, on the basis of logistics network. It is found that C - PSO algorithm can be well applied to the location problem of the specific practice, and provide feasible technical support for location optimization of science and technology resources.

KEYWORDS

Large-scale scientific instruments; Location optimization; Logistics network; Chaotic particle swarm; CLC Number: F224; G311 Document Code: A.

INTRODUCTION

With the coming of the era of knowledge economy and the rapid development of high-tech industry, science and technology has become a major force determining economic and social development[1](Zhao, 2012). In order to promote economic growth, all countries and regions have increased resource investment in scientific and technological activities and lots of attention is paid to technological innovation and the fostering of high and new technology industry. The innovation-driven development strategy was put forward in the Report of the Eighteenth National Congress of the CPC. The strategy focuses on improving knowledge innovation system, implementing major national science and technology projects and carrying out knowledge and intellectual property strategy. The strategy aims to mobilize all wisdom and strength of the whole society to innovative development. For scientific and technological industry, the layout of large-scale scientific instruments is a very critical issue. Mainstream economics highly values "3W", namely, why to produce, what to produce and for whom to produce, but it has ignored another key "W", where to produce. Therefore, the layout of large-scale scientific instruments seems extremely important.

Current researches on this problem mainly focus on the operating efficiency of scientific and technological industry. With a view to give full play to the comprehensive efficiency of large-scale scientific instruments and improve the regional innovation capability, Xia, Yuan and Wang[2] (2005) elaborated the three operating mechanisms and five safeguard measures for ensuring the sharing and sustainable and highly efficient operation of instrument and equipment resources. Through literature review, Xiao[3] (2010) study the relevant literature on large-scale scientific instruments published in China during the period from 1987 to 2006 and put forward the concept of scientific and technical innovation cluster in high-tech industry based on the characteristics of the industry cluster in high-tech industry. The general theories and characteristics in the layout of the large-scale scientific instruments in high and new technology industry were discussed. By establishing synthetic location entropy index and using the data of 2007 as the samples, he studied the allocation pattern of the large-scale scientific instruments in China's five industries, including pharmaceutical industry, aerospace & aircraft manufacturing industry, electronics and communication device manufacturing industry, computer and office equipment manufacturing industry and instrument manufacturing industry. It was pointed out that the large-scale scientific instruments in China's three industries, which are aerospace & aircraft manufacturing industry, electronics and communication device industry and computer and office equipment manufacturing industry is currently in such a configuration that the former one far outperforms the latter two, with apparent gap in the allocation of space resources. With the regional innovation systems in Shaanxi, Sichuan and Chongqing as the research objects, Yang[4] (2009) held the view that the construction should take full advantage of favorable conditions, giving priority to releasing the national scientific and technological energy of the district. He also identified the regional "embeddedness" of the layout of national large-scale scientific instruments, the immobility of technological capabilities and the "space limitations" in scientific knowledge spillover. China should rely on the path of the regionalization of national innovation system guided by ideological innovation so as to overcome the mistaken ideas of implementing scientific and technological innovation for its own sake and emphasizing the targets of national innovation system instead of scientific and technological industrialization and regional innovation system construction. On the basis of defining the connotations of the layout efficiency and its evaluation for large-scale scientific instruments oriented toward independent innovation, Zhao[1] (2012) analyzed the functions and principles of the evaluation of the layout efficiency of large-scale scientific instruments, established the evaluation model for the layout efficiency of regional large-scale scientific instruments and conducted an empirical study on the evaluation of the layout efficiency of large-scale scientific instrument in the 31 provinces across China in 2009. The research results lead to the conclusion that in the future, China can further improve the layout efficiency of large-scale scientific instruments by optimizing the layout environment for large-scale scientific instruments and improving the output capacity of large-scale scientific instruments. A comprehensive evaluation of the utilization of large-scale scientific instruments is the foundation for efficiently using large-scale scientific instruments and equipments. With Rank Sum Ratio method and based on the relevant data on the status quo of China's large-scale scientific instrument resources obtained by a program of National Science and Technology Infrastructure Center (2009), Zhang, Han, Zhao and Yang[5] (2013) conducted a comprehensive evaluation of the utilization of large-scale instruments in China. With the measurement of the layout efficiency of large-scale scientific instruments in farming as the principal line, Yang[6] (2011) conducted an empirical test on the intrinsic relationship between the large-scale agricultural instruments and the agricultural economic growth and measured the layout efficiency of large-scale scientific instruments in China's agricultural scientific research institutions and agricultural colleges and universities. He also estimated the layout efficiency of large-scale agricultural scientific instruments in eight agricultural ecological regions and analyzed the relevant influencing factors.

Other scholars also studied other specific industries and regions. Taking China's pharmaceutical industry as an example, Xiao, Li and Xing[7] (2010) relied on the location quotient theory in regional economics to establish synthetic location quotient to analyze the provincial layout of large-scale scientific instruments in China's pharmaceutical industry and medical equipment and instrument manufacturing industry. With the large-scale scientific instruments in provincial high-tech industries in China as the research objects, Xiao, Li and Hu[8] (2010) established a calculation model for synthetic location quotient to calculate the synthetic location entropy for China's provincial pharmaceutical manufacturing industry, aerospace & aircraft manufacturing industry, electronics and communication device manufacturing industry, computer and office equipment manufacturing industry and medical equipment and instrument manufacturing industry. Furthermore, aiming at the vulnerability to locally optimal solution in standard particle swarm optimization, Li[9] (2014) put forward the site selection strategy for logistics distribution center based on catfish effect particle swarm optimization (CFPSO). After the verification of algorithm performance by means of simulation experiment, it was discovered that compared with genetic algorithm and standard particle swarm algorithm, CFPSO algorithm can achieve better site selection scheme for logistics distribution center, showing greater superiority. The improved particle swarm optimization is represented by Wang[10] (2009), which offers a better solution for different constraints in the optimization problem. This method is widely used in the swarm robots, evolutionary computation and so on.

The existing researches have offered extremely inspirational perspective and way of thinking for studying the layout of large-scale scientific instruments, but there can be better solution to the concrete issues in relation to site selection and layout. As for the layout of large-scale scientific instruments, the classical method originates from Weber's industrial location theory[11] (Weber, 1965). The "gravity map" method based on transportation cost explores the industrial location from the perspective of logistics network. This idea is of great inspirational significance for the layout of large-scale scientific instruments. Therefore, the author employed a modern technology, chaotic particle swarm optimization, to conduct an in-depth and realistically significant analysis on the layout of large-scale scientific instruments from the perspective of logistics network[12,13] based on industrial location theory.

PARTICLE SWARM METHOD FOR THE LAYOUT OF LARGE-SCALE SCIENTIFIC INSTRUMENTS FROM THE PERSPECTIVE OF LOGISTICS NETWORK

(1) Particle swarm optimization

In particle swarm algorithm, each example is compared to an individual in a swarm of fish. Particle swarm optimization method is an optimization technique based on population, in which species is called particle swarm. Particle swarm includes N particles, which move in a D -dimension search space. The location of the i -th particle is defined as $x_i = \left(x_{i1}, x_{i2}, ..., x_{iD}\right)$. The velocity of the i -th particle can be written as vector $v_i = \left(v_{i1}, v_{i2}, ..., v_{iD}\right)$. The domains of definition for location and velocity are $\left[X_{\min}, X_{\max}\right]^D$ and $\left[V_{\min}, V_{\max}\right]^D$,respectively. Each and every particle coexists with each other and evolves based on the sharing of knowledge with adjacent particles. Each particle can make full use of its own knowledge and the knowledge obtained through the particle swarm to seek the optimal solution. The optimal location occurring before can be defined as the optimal position location $p_i = \left(p_{i1}, p_{i2}, ..., p_{iD}\right)$, with the value of $pbest_i$. The optimal value in the $pbest_i$ of all individuals can be defined as the global optimal location $g = \left(g_1, g_2, ..., g_D\right)$, which is called $gbest$. The initial population for particle swarm algorithm is random particle. Later, the algorithm seeks the optimal solution by constant regeneration. In each generation, the location and velocity of the i -th particle will be updated with the $pbest_i$ and $gbest$ of the population. The updating equation can be expressed as:

$$v_{id}^N = w \times v_{id}^O + c_1 \times r_1 \times \left(pbest_{id} - x_{id}^O\right) + c_2 \times r_2 \times \left(gbest_d - x_{id}^O\right) \quad \textbf{(1)}$$

$$x_{id}^N = x_{id}^O + v_{id}^N \quad \textbf{(2)}$$

where r_1 and r_2 represent the random numbers in the interval of (0, 1); c_1 and c_2 represent the accelerating factors, which control the distance that a single generation can move; v_{id}^N and v_{id}^O represent the velocity of new and the old particles, respectively; x_{id}^N and x_{id}^O represent the new and the current locations of the particle, respectively. Inertia weight w controls the impact of the past velocity of particles on current velocity. Generally speaking, inertia weight will undergo linear decreasing from 0.9 to 0.4, which can effectively balance the local and global search capabilities of particle swarm. Inertia weight w can be expressed as:

$$w = \left(w_{\max} - w_{\min}\right) \times \frac{I_{\max} - I_i}{I_{\max}} + w_{\min} \quad \textbf{(3)}$$

In equation 3, $w_{\max}$ and $w_{\min}$ are 0.9 and 0.4, respectively. $I_{\max}$ represents the maximal number of iterations.

(2) Chaotic particle swarm algorithm (C-PSO)

In PSO algorithm, parameter w, r_1, r_2 is the key variable influencing the convergence behavior[14]. Inertia weight controls the balance between global search and local search capabilities. Greater inertia weight leads to global search, while smaller inertia weight tends to cause local search (Tsoulos and Stavrakoudis, 2010). For this reason, the search process usually adopts the inertia weight that decreases linearly from 0.9 to 0.4. Logistics network usually adopts logical map and the mapping of chaotic behavior and chaotic sequences can be rapidly generated and are easy to store, so there is no need to store long sequences. In C-PSO, parameter r_1 and r_2 are modified by the logical map based on the following equation.

$$Cr_{(t+1)} = k \times Cr_{(t)} \times \left(1 - Cr_{(t)}\right) \tag{4}$$

In Equation (4), $Cr_{(0)}$ is generated randomly and is not equal to $\{0, 0.25, 0.50, 0.75, 1\}$. Besides, k is equal to 4. As t tends towards infinity, the driving parameters of logical map k controls the behavior of $Cr_{(t)}$.

Now the velocity updating equation of C-PSO can be expressed as:

$$v_{id}^{N} = w \times v_{id}^{O} + c_1 \times C_r \times \left(pbest_{id} - x_{id}^{O}\right) + c_2 \times \left(1 - C_r\right) \times \left(gbest_d - x_{id}^{O}\right) \tag{5}$$

In Equation (5), C_r is the function of the result of the logical map, with the value ranging from 0 to 1. Given the scale of large-scale scientific instruments, the following are the concrete steps for the C-PSO algorithm for optimal layout of scientific resources (Chuang et al., 2011): step 1, configure parameters for C-PSO algorithm, including w, c_1, particle number, velocity and location; step 2, generate initial particle swarm by means of homogenization method to ensure the uniform distribution of particle cluster; step 3, calculate the fitness value of the particle to further determine the optimal value of the particle and the particle cluster; step 4, determine the values of the driving parameters and calculate the updated velocity and location of the particle; step 5, if the fitness value of the example is higher than that of the particle swarm, the value of the particle swarm will be updated; step 6, within the maximal number of iterations, the optimal location of large-scale scientific instrument is obtained, otherwise return to Step 2 to continue the search for the optimal position.

NUMERICAL SIMULATION

(1) Results of numerical simulation using the benchmark function of layout and site selection model for large-scale scientific instruments

In order to demonstrate the validity and performance of particle swarm algorithm in optimization problem, we propose ten representative benchmark functions for verification. The ten benchmark functions are listed below:

Rosenbrock benchmark function:

$$f_1(x) = \sum_{i=1}^{D-1}\left[100\left(x_{i+1} - x_i^2\right)^2 + \left(x_i - 1\right)^2\right] \tag{6}$$

Rastrigrin function:

$$f_2(x) = \sum_{i=1}^{D}\left[x_i^2 - 10\cos\left(2\pi x_i\right) + 10\right] \tag{7}$$

Griewark function:

$$f_3(x) = \frac{1}{4000}\sum_{i=1}^{D} x_i^2 - \prod_{i=1}^{D}\cos\left(\frac{x_i}{\sqrt{i}}\right) + 1 \tag{8}$$

Rosenbrock function:

$$f_4(x)=\sum_{i=1}^{D}x_i^2 \quad \textbf{(9)}$$

Ackley function:

$$f_5(x)=-20\exp\left(-0.2\sqrt{\frac{\sum_{i=1}^{D}x_i^2}{D}}\right)-\exp\left(\frac{\sum_{i=1}^{D}\cos(2\pi x_i)}{D}\right)+20+e \quad \textbf{(10)}$$

Schwefel function:

$$f_6(x)=418.9809D-\sum_{i=1}^{D}x_i\sin\left(\sqrt{|x_i|}\right) \quad \textbf{(11)}$$

Ellipsoid function:

$$f_7(x)=\sum_{i=1}^{D}ix_i^2 \quad \textbf{(12)}$$

SDP (sum of difference power) function:

$$f_8(x)=\sum_{i=1}^{D}|x_i|^{i+1} \quad \textbf{(13)}$$

Cigar function:

$$f_9(x)=x_1^2+10\sum_{i=1}^{D}x_i^2 \quad \textbf{(14)}$$

Ridge function:

$$f_{10}(x)=\sum_{i=1}^{D}\sum_{j=1}^{i}x_j^2 \quad \textbf{(15)}$$

Since the results by C-PSO algorithm are superior, in the following we only present the results of numerical simulation using C-PSO algorithm.

TABLE 1 : Results of numerical simulation

Population number	DIM	Number of iterations	Rosenbrock	Rastrigrin	Griewark	Sphere
20	10	1000	28.2±426.3	4.4±2.8	0.06±0.05	2.02e-41±1.56e-40
	20	1500	27.8±248.1	12.7±7.0	0.002±0.009	3.80e-14±1.20e-12
	30	2000	27.7±43.1	22.7±10.9	0.36±5.7	40.0±0631.5

40	10	1000	7.2±39.5	2.9±1.8	0.07±0.04	4.56e-21±1.44e-19
	20	1500	25.0±251.5	10.0±5.7	0.1±0.8	10.0±316.2
	30	2000	42.3±338.1	18.8±9.1	0.3±1.0	30.0±547.2
80	10	1000	9.9±88.9	2.1±1.4	0.06±0.03	3.19e-08±1.01e-06
	20	1500	15.3±7.3	8.24.4	0.01±0.04	1.21e-03±3.83e-02
	30	2000	27.9±83.3	15.6±7.9	0.09±2.9	10.0±0316.2
160	10	1000	7.0±56.9	1.3±1.3	0.06±0.03	5.19e-07±1.62e-05
	20	1500	26.7±343.9	6.7±4.0	0.02±0.04	6.04e-04±1.29e-02
	30	2000	27.1±57.8	13.1±8.3	0.002±0.04	1.62e-02±5.11e-01

TABLE 2 : Results of numerical simulation

Number of populations	DIM	Number of iterations	Ackley	Schwefel	Ellipsoid
20	10	1000	8.92e-07±2.82e-05	1894.348±163.581	600.00±2398.979
	20	1500	2.91e-14±5.79e-13	4307.703±182.864	400.00±1979.487
	30	2000	1.74e-14±4.58e-15	6694.397±193.135	2.47e-23±1.74e-22
40	10	1000	4.69e-15±9.29e-16	1754.631±138.071	1.08e-52±4.86e-52
	20	1500	8.39e-15±2.29e-15	4146.448±159.319	1400.00±3505.098
	30	2000	1.44e-14±4.17e-15	6549.629±177.332	400.00±1979.487
80	10	1000	4.49e-15±5.25e-16	1636.762±130.128	4.27e-59±1.19e-58
	20	1500	7.91e-15±2.03e-15	4026.056±142.332	800.00±2740.475
	30	2000	1.28e-14±4.06e-15	6406.896±151.301	200.00±1414.214
160	10	1000	4.44e-15±3.18e-16	1539.963±115.339	4.88e-64±2.60e-63
	20	1500	7.56e-15±1.70e-15	3913.073±112.881	1200.00±3282.607
	30	2000	1.19e-14±4.08e-15	6290.060±139.653	600.00±2398.979

TABLE 3 : Results of numerical simulation

Number of populations	DIM	Number of iterations	SDP	Cigar	Ridge
20	10	1000	0.060±0.424	1000.00±3030.458	9.79e-42±3.58e-41
	20	1500	1.77e-42±8.41e-42	4.38e-29±2.34e-28	1.78e-29±9.16e-29
	30	2000	6.77e-35±3.77e-34	5.57e-22±3.94e-21	1.32e-22±9.35e-22
40	10	1000	1.94e-60±9.07e-60	600.00±2398.979	2.07e-48±6.11e-48
	20	1500	1.54e-50±9.84e-50	400.00±1979.487	4.16e-34±2.40e-33
	30	2000	7.43e-11±5.25e-10	7.70e-29±5.45e-28	1.12e-29±7.90e-29
80	10	1000	0.060±0.424	400.00±1979.487	1.80e-53±8.40e-53

	20	1500	1.52e-58±7.82e-58	200.00±1414.214	3.90e-40±1.62e-39
	30	2000	1.29e-17±9.15e-17	200.00±1414.214	2.17e-33±1.28e-32
160	10	1000	3.40e-70±9.60e-70	3.95e-58±1.60e-57	5.07e-59±1.81e-58
	20	1500	9.18e-11±6.49e-10	400.00±1979.487	9.24e-31±6.53e-30
	30	2000	3.99e-35±2.82e-34	400.00±1979.487	1.64e-37±1.04e-36

(2) Simulation using layout and site selection model for large-scale scientific instruments

The layout and site selection model for large-scale scientific instruments is solved by C-PSO using different benchmark functions. The model was run on Win 7 with Intel Core2 2.6GCPU and 6G memory. Simulation experiment was carried out under Matlab2009 environment. In the layout and site selection model, the key problem is to determine the amount of demand for large-scale scientific instruments and customer address. We used high technology.

The amount of demand for large-scale scientific instruments and customer addresses are given in TABLE 4.

TABLE 4 : Site and amount of demands for large-scale scientific instruments

Customer address	X	Y	Amount of demand for large-scale scientific instruments	Customer address	X	Y	Amount of demand for large-scale scientific instruments
1	2887	1432	11	16	3854	1953	9
2	3689	1337	14	17	3203	2845	22
3	3990	2579	15	18	3674	3369	25
4	3219	2498	18	19	4219	2217	36
5	2908	2206	22	20	3562	2875	14
6	1408	3205	13	20	3218	1446	21
7	2885	2156	13	21	4209	2143	22
8	3109	1684	8	22	4709	3210	26
9	3219	2509	6	23	2578	1374	25
10	2950	1278	31	24	4409	1785	32
11	4431	1786	45	25	3091	1884	35
12	1411	3407	25	26	3215	3456	47
13	2189	1258	18	28	2419	2665	15
14	4144	2409	17	29	2876	1228	11
15	2943	1328	22	30	2877	2256	17

C-PSO algorithm is used to solve the layout and site selection problem for large-scale scientific instruments in TABLE 4. Six sites are selected out of 30 customers having demand for large-scale scientific instruments as the sites in the layout. Then the schematic diagram of layout and site selection of large-scale scientific instruments is obtained. It can be seen from Figure 1 that the scheme of layout and site selection of large-scale scientific instruments using C-PSO algorithm is superior. The block represents the site in the layout of large-scale scientific instruments; dot represents the customer having a demand for large-scale scientific instruments; curved line represents the demand for large-scale scientific instruments.

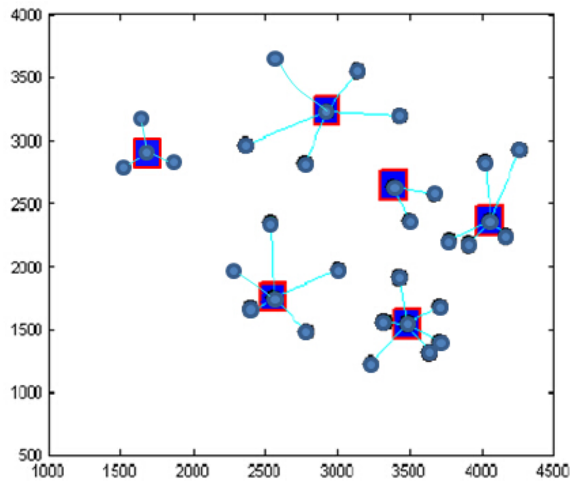

Figure 1 : Scheme of layout and site selection of large-scale scientific instruments under C-PSO algorithm

In fact, the calculation of this site selection scheme has representativeness. For specific industry of large-scale scientific instruments and high-tech industry, once the demand and geographical positions of the customer are known by survey, the C-PSO algorithm can be employed to obtain the scheme of layout and site selection of large-scale scientific instruments.

CONCLUSION

It is generally agreed that technical industry and large-scale scientific instruments boost the economic and social development. However, the existing researches mostly deal with the operational efficiency of large-scale scientific instrument industry, but seldom concern with the space operation efficiency of large-scale scientific instruments, that is, the problem of spatial layout of large-scale scientific instruments.

In this article, we adopt the perspective of logistics network of gravity map in Weber's industrial location theory. Chaotic particle swarm algorithm is employed to solve the layout of large-scale scientific instruments. This research method provides great inspiration for the layout problem of large-scale scientific instruments. It is found by our research that C-PSO algorithm can be effectively applied in the layout of large-scale scientific instruments, providing practical technical support for the layout and site selection of large-scale scientific instruments.

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