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INDUSTRIAL CLUSTER EVOLUTION BASED ON PATH DEPENDENCE COMBINING WITH PSO ALGORITHM

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РОЗВИТОК ПРОМИСЛОВИХ КЛАСТЕРІВ НА ОСНОВІ ЗАЛЕЖНОСТІ ВІД ПОПЕРЕДНЬОГО РОЗВИТКУ В КОМБІНАЦІЇ З РОЄВИМ АЛГОРИТМОМ

Purpose. Specific to the existing defects of the industrial cluster research studies at home and abroad, the paper analyzed the evolutionary process based on the PSO algorithm.

Methodology. An industrial cluster evolution mold was established based on path dependence combining with PSO algorithm. A simulation analysis was performed on the mold algorithm established in the paper.

Findings. The results have revealed that the mold presented in the paper can **be** applied for quantitative and qualitative analysis of the evolvement rule of the industrial cluster. In addition, it can be seen from the case simulation results that with appropriate governmental macro regulation and control, as well as equilibrium state of competition and cooperation between enterprises, the eventual industrial cluster will mainly tend to be an enterprise model maintaining the existing market share and expanding production. When the governmental macro regulation and control is over-sized or excessively small, or the competition and cooperation between enterprises are under non-equilibrium state, the final industrial cluster will tend to be an enterprise model to develop new products and new markets.

Originality. While studying the evolutionary process of the industrial **cluster**, the existing research studies still remain the qualitative discussion stage for the production process and evolution rules of the industrial cluster. The research studies are not sufficiently profound and can hardly describe the dynamic effects of the industrial cluster quantitatively. Consequently, the paper correlates the PSO algorithm and the self-organizing characteristics of the industrial cluster. Combined with the theory of path dependence, it successfully simulated the evolution of the industrial cluster by adopting the PSO algorithm.

Practical value. The simulation analysis result of the paper can **effectively** analyze the evolutionary process of the industrial cluster. It can qualitatively simulate the evolution characteristics and rules of the industrial cluster. Furthermore, it can provide a new analysis thought for the academic research of the industrial cluster.

Keywords: *industrial cluster, particle swarm, evolutional law, path dependence*

Introduction. Industrial cluster is a new trend of the development of the regional economy nowadays. It does not only constitute the basic space frame for the present world economy, but also is a decisive factor for national or regional competitiveness. The pharmaceutical industry, as a key industry with the most supports from various countries, will receive significant opportunity from cluster development [1–2].

The industrial cluster innovation ability [3–4] refers to the organic integration of abilities on knowledge accumulation, competition and cooperation, development and innovation of enterprises in the cluster and other organizations. The integration objects include elements such as information knowledge technology, fund experience relationship culture, etc.; the organizations carrying out the integration include companies, intermediaries, university scientific research institutions and the government. The integration is aimed at mutual benefit and development and is to innovate continuously thus to improve enterprise cluster competitiveness and realize the sustainable development of industries and enterprises in the cluster. Technology innovation is the foundation and precondition of the sustainable development of the pharmaceutical industry, and is an essential method for the pharmaceutical industry to enhance the competitive preponderance. The innovation ability of the industrial cluster is the driving force to promote the development of the enterprises in the cluster. In order to keep at the forefront of the times, an industrial cluster shall keep consistent theory innovation and technological innovation unless being eliminated by the fierce market competition. The development degree and size of a cluster is closely related to the innovation ability of the cluster. Through improving the innovation ability of the industrial cluster, it can realize cost reduction, competitiveness enhancement and obtain higher economic benefits.

Although certain achievements have been made on the studies of industrial cluster innovation ability [5–6], most of the study objects are in relatively developed areas. There are fewer research studies on the industry clusters in underdeveloped regions. Furthermore, the existing studies still remain at the qualitative discussion stage for the production process and evolution rule of industrial cluster. The research results are not sufficiently profound and can hardly describe the dynamic effects of industrial cluster quantitatively. Consequently, the research studies still remain in case analysis of the existing industrial clusters without a mature algorithm to describe the industry cluster.

Therefore, the paper focused on the evolution of the industrial cluster. It performed detailed analysis on the industrial cluster based on self-organizing path dependence, and proposed an algorithm to solve an evolution mechanism of the industrial cluster by combining the path dependence theory with the PSO algorithm. In addition, by setting the evolution of an actual medical industry cluster as an example, it analyzed the path evolution process and laws of the industrial cluster, carried out in-depth studies on the theoretical basis and implementation approach, and provided a new analysis thought for the academic research of the industrial cluster through analyzing the common characteristics of the industrial cluster and the PSO algorithm and eventually based on difference parameters of the PSO algorithm.

Industrial cluster evolution algorithm based on particle swarm optimization. ***Correlation between.***

Standard PSO algorithm. A standard PSO algorithm [7–8] is a heuristic optimization calculation model. For a PSO algorithm with a determined objective function, let us assume that there is a particle swarm including M particles during the solution process, the search space dimension of the particle swarm is D and particle i is a particle included in the group, the state property value of particle i at t is shown in the formula 1–4 as follows:

1. Position status

$$X_i^t = (X_{i1}^t, X_{i2}^t, X_{i3}^t, \ldots, X_{id}^t)^T;$$
$$X_{id}^t \in (X_{\min}, X_{\max}).$$

Where $X_{\min}$ and $X_{\max}$ are the lower limit and the upper limit of the coordinate position respectively.

2. Speed state

$$V_i^t = (V_{i1}^t, V_{i2}^t, V_{i3}^t, \ldots, V_{id}^t)^T;$$
$$V_{id}^t \in (V_{\min}, V_{\max}).$$

Where $V_{\min}$ and $V_{\max}$ are the lower limit and the upper limit of speed respectively.

3. Particle-best

$$P_i^t = (P_{i1}^t, P_{i2}^t, P_{i3}^t, \ldots, P_{id}^t)^T.$$

4. Global optimum

$$P_g^t = (P_{g1}^t, P_{g2}^t, P_{g3}^t, \ldots, P_{gd}^t)^T.$$

The above is the state property value of particle at t, and at $t + 1$ it can be updated at iteration through formula

$$V_{id}^{t+1} = wV_{id}^t + c_1 r_1 (P_{id}^t - X_{id}^t) + c_2 r_2 (P_{gd}^t - X_{id}^t);$$
$$X_{id}^{t+1} = X_{id}^t + V_{id}^{t+1},$$

where w is the inertia weight value of the PSO algorithm.

While the particle is iterated from t to $t + 1$, it mainly includes three core parts. The first part shows the speed of the particle at t, which means that the speed at $t + 1$ inherits that at t; the second part presents self-cognition that the particle will adjust the flight state according to the historical optimal location while taking its accumulated experience of flight into consideration; the third part is social information. Except for its own experience, the particle will reference to the flight information of the whole population, and adjust the flight state according to the optimal location of the whole population.

Common characteristics of industrial cluster and PSO algorithm. In fact, the industrial cluster is a kind of self-organization path dependence system. The formation of the industrial cluster is also under continuous evolvement of the open dissipative structure. And the PSO algorithm is a self-organizing algorithm. The optimization process is in the form of self-organization. If we consider the enterprises in a cluster as the particles of the PSO algorithm, the position of the cluster is the position with the most competitiveness of the cluster. In addition, if we consider it as the optimal position of the PSO algorithm, the agglomeration process of the industrial cluster can be considered as the optimization process of particle swarm. Consequently, the optimization process of particle swarm is connected to the grouping of the industrial cluster. The following will carry out detailed analysis from the perspective of PSO algorithm parameters.

1. *Parameter w.*

For particle swarm, it is presented as the inertia weight value of the particle swarm algorithm. The parameter can adjust the effect of the particle swarm algorithm. The higher inertia weight coefficient value is, the stronger speed value dependency will be obtained from the previous iteration. The higher global searching ability of the algorithm will be. On the contrary, it is more conducive to local search ability of the algorithm. While for industrial cluster process, this parameter can be regarded as the macroscopic coordination role of countries to participate in the activities of the industrial cluster. If the government is involved in a cluster economic activity, when the value w is oversized, namely too much macroscopic readjustment and control, it will be in violation of the basic rules of the market economy. On the contrary, if the value w is too small, it cannot make up the loss arising from the unbalanced market.

2. *Parameter* c_1.

For particle swarm, it presents the "cognition" part of the particle swarm algorithm. Namely, in case of low efficiency of the particle swarm seeking for the optimal value, there is no information communication between particles during the optimizing process of particle swarms, namely no sharing of the information society. Each particle performs iteration optimizing in its own way. While for industrial cluster process, it presents the economic benefit of the industrial cluster during evolutionary process. Such benefit is a type of pure predatory competition in the market. No cooperation exists among industries, but only mutual competition process. Throughout the process, the industrial cluster does not consider the bearing capacity of the social environment to carry out economic activities forcibly.

3. *Parameter* c_2.

For particle swarm, it presents the "social" part of the particle swarm algorithm. When there is only "social" part in the Particle Swarm Optimization but no "cognition" part, although the convergence rate of particle is quicker and is easier to converge an optimal value due to better social information sharing among particles, the Algorithm lacks an "overall" view due to the missing of "cognition" part, which means that the algorithm is prone to local optimum. While for industrial cluster process, it presents cooperation, from the generic concept in the paper, among enterprises of the industrial cluster. Such cooperation includes that between enterprises, enterprise and the government, scientific research institutions and even two governments. The participants or managers of industrial cluster pay more attention to how to keep the cluster to be under a benign and sustainable state thus to realize re-circulation of cluster scale economy.

Establishment of industrial cluster evolution based on particle swarm optimization. Through the above internal association analysis of particle swarm parameters and the industrial cluster, in order to simulate the evolution of industrial cluster by means of the PSO algorithm, the industrial cluster shall be micronized. Namely, the comprehensive index of the industrial cluster is the object function value of the PSO algorithm. The geographic coordinate position of the industrial cluster is that of particle searching space in the PSO algorithm. The "cooperation" and "competition" existing among enterprises of the cluster can be realized through "cognition" and "society" part of the PSO algorithm.

In conclusion, the fireworks model based on particle swarm of the industrial cluster, the iterative formula of objective function and basic speed and position is as shown in (1). The variables in the formula show characteristics of the industrial cluster. And the iteration process of the algorithm is to be calculated in accordance with the SPSO algorithm.

$$\max Z = f(x,y);$$
$$V_{id}^{t+1} = wV_{id}^{t} + c_1 r_1 (P_{id}^{t} - X_{id}^{t}) + c_2 r_2 (P_{gd}^{t} - X_{id}^{t}); \quad (1)$$
$$X_{id}^{t+1} = X_{id}^{t} + V_{id}^{t+1}.$$

The new practical significance of the variables in (1) is as shown below:

- W presents interference effects of the government during the cluster evolution process, such as national relevant policies and macro-control;
- X presents relevant indicators affecting the industrial cluster, namely the position on the coordinate axis (x, y);
- c_1, c_2 present competition and cooperation of the industrial cluster during the economic activity process;
- P_{id}^{t}, P_{gd}^{t} present the optimal position searched from individual particles and particle swarm respectively;
- Z presents the comprehensive index value of the industrial cluster.

Model applications and result analysis. ***Calculation of industrial cluster influencing index.*** The paper sets Heilongjiang province pharmaceutical industry as an example. The survey data access method is through a 100 questionnaire survey specific to each enterprise and inner staff. The mode of each index of the questionnaire survey shall be determined as final index score. For module *A* and *B*, they are statistical data of the company while for module *C*, fuzzy grade evaluation is adopted. The score 0 indicates "strong disagreement"; the score 1 indicates "disagree"; score 2 indicates "neither agree nor disagree"; score 3 indicates "partially agree"; score 4 indicates "agree"; and score 5 indicates "highly agree". The index information of the questionnaire survey specific to each enterprise is as shown in Table 1.

Table 1

Core index of questionnaire survey

No.	Module	Module index
A	Suppliers of the company	A1: Long-term cooperation A2: Long-term cooperation units within the province A3: Purchase rate under long-term cooperation A4: Purchase rate under long-term cooperation within the province
B	Customer units of the company	B1: Number of companies with long-term cooperation B2: Number of companies with long-term cooperation within the province B3: Sales ratio of long-term cooperation B4: Sales ratio of long-term cooperation within the province
C	What strategic objectives are the most important for the company in 3–5 years	C1: To maintain the existing market share C2: Preponderance to develop the new technology and acquire new technology C3: To develop new products and new markets C4: To expand production (building new plants, buying new equipment, etc.)

Table 2

Various parameter values of the enterprise

Enterprise	$A1$	$A2$	$A3$	$A4$	$B1$	$B2$	$B3$	$B4$	$C1$	$C2$	$C3$	$C4$
1	23	5	0.9	0.2	20	3	1	0.18	2	5	4	5
2	28	4	0.8	0.15	103	15	0.92	0.08	5	5	5	5
3	50	5	0.7	0.3	100	50	0.7	0.4	4	4	5	3
4	10	5	0.65	0.55	50	10	0.45	0.35	4	4	5	3
5	15	9	0.9	0.2	30	10	0.33	0.39	5	5	4	4
6	95	37	0.6	0.35	294	111	0.8	0.4	5	5	5	5
7	4	1	0.8	0.2	50	5	0.8	0.2	5	4	5	5
8	20	5	0.72	0.2	100	20	0.85	0.1	4	5	5	2
9	21	10	0.85	0.47	172	24	0.48	0.11	4	4	3	4
10	8	3	0.8	0.3	14	7	0.85	0.3	2	4	4	5
11	20	5	0.8	0.3	210	60	0.9	0.1	0	5	5	3
12	5	5	0.4	0.2	30	10	0.8	0.3	4	3	3	4
13	60	10	0.8	0.4	70	20	0.8	0.4	5	5	5	5
14	69	7	0.7	0.1	54	7	0.8	0.3	4	5	5	4
15	63	13	0.27	0.31	215	63	0.72	0.63	0	5	5	5
16	35	10	0.6	0.3	30	6	0.7	0.3	4	3	5	5
17	1	1	0.9	0.8	18	14	0.9	0.75	5	5	5	5
18	2	2	0.6	0.1	2	2	0.6	0.2	5	5	5	5
19	8	1	0.8	0.1	30	10	0.9	0.7	5	5	5	5
20	7	5	0.8	0.65	3	2	0.8	0.65	5	5	5	5
21	3	1	0.65	0.25	1	1	0.9	0.3	1	2	3	2

The survey on 21 pharmaceutical enterprises of Heilongjiang was carried out through the above questionnaire survey. The sample data index obtained is shown in Table 2.

In order to reflect the industrial evolution law of various enterprises, this paper defined the following several key factors influencing the industrial cluster which are shown below:

1. Purchase rate of long-term cooperation ($A3$)* Long-term cooperation sales proportion = cooperation lasting degree of procurement and sales network of the enterprise, hereinafter referred to as cooperation lasting degree, is shown in (2)

$$x = A3 * B3. \quad (2)$$

2. Purchase rate under long-term cooperation within the province ($A4$)* Sales ratio of long-term cooperation within the province ($B4$) = Localization factor of the enterprise, is shown in (3)

$$y = A4 * B4. \quad (3)$$

3. We take maintaining the existing market share ($C1$) and expanding production ($C4$) as inert evaluation index, preponderance to develop the new technology and acquire new technology ($C2$), and develop new products and new markets ($C3$) belongs to innovation evaluation indexes. Consequently, the strategic decision freedom degree of enterprise is shown in (4) below

$$F = \frac{C1 + C4}{C1 + C2 + C3 + C4}. \quad (4)$$

We calculate the enterprise index data as shown in Table 2 above to obtain the industrial cluster influencing index in Table 3.

We perform fitting by taking cooperation lasting degree X and localization factor y as an independent variable, and strategic decision freedom degree of en-

Table 3

Strategic decision freedom degree of enterprise F, cooperation lasting degree X and localization factor y result

Enterprise	Cooperation lasting degree X	Localization factor y	Strategic decision freedom degre of enterprise F
1	0.90	0.036	0.4375
2	0.736	0.012	0.5000
3	0.49	0.120	0.4375
4	0.2925	0.1925	0.4375
5	0.297	0.078	0.5000
6	0.48	0.140	0.5000
7	0.64	0.040	0.5263
8	0.612	0.020	0.375
9	0.408	0.0517	0.5333
10	0.68	0.090	0.4667
11	0.72	0.030	0.2308
12	0.32	0.060	0.5714
13	0.64	0.160	0.5000
14	0.56	0.030	0.4444
15	0.1944	0.1953	0.3333
16	0.42	0.09	0.5294
17	0.81	0.60	0.5000
18	0.36	0.02	0.5000
19	0.72	0.07	0.5000
20	0.64	0.4225	0.5000
21	0.585	0.075	0.375

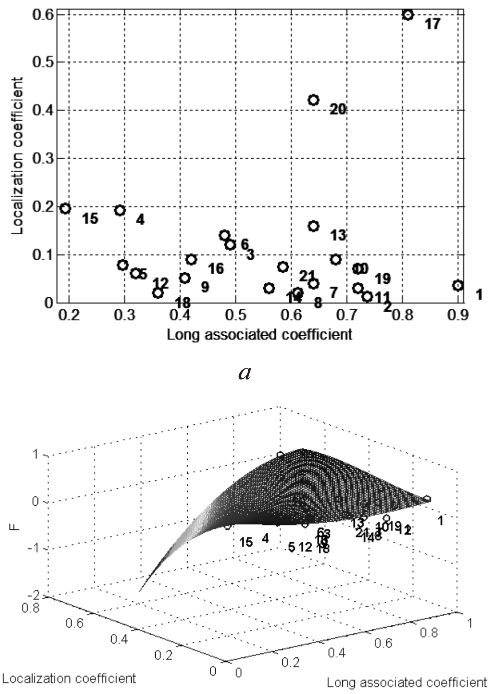
Table 4

Fitting results and related fitting parameters

Parameter	Parameter value
p1	1.3702
p2	–2.5494
p3	–3.1597
p4	1.6964
p5	10.3813
p6	–2.6090
p7	–2.6291
p8	–7.2639
p9	6.4360
p10	–2.6291
p11	0.0179
Root of Mean Square Error (RMSE)	0.2704
Sum of Square Error (SSE)	0.00731
R-Square	0.9860

terprise *F* as a dependent variable. The fitting function is shown in (5) below. The fitting results of related parameters are shown in Table 4 below. The distribution results of cooperation lasting degree *X* and localization factor *y* as an independent variable, and strategic decision freedom degree of enterprise *F* of Heilongjiang medicine industry are shown in Fig. 1 below.

$$f(x,y) = p_1 + p_2x + p_3y + p_4x^2 + p_5xy + p_6y^2 + p_7x^3 + p_8x^2y + p_9xy^2 + p_{10}y^3 + p_{11}\frac{1}{1-e^{x^2+y^2}}. \quad (5)$$



a

b

Fig. 1. Fitting distribution results:

a — shows the distribution of cooperation lasting degree X and localization factor y; b — shows the distribution of strategic decision freedom degree F

Simulation analysis of particle swarm. We perform iteration optimizing for Formula 10 with the PSO algorithm to get the maximum value. We set the number of evolutionary iteration as 100, the total amount of particle swarm as 50, and the initial position coordinates of particle as (0.4, 0.4).

1. When $c_1 = 1$, $c_2 = 1$, and w is increasing progressively, the interference effect of the government is increasing, the simulation result is shown in Table 5 and Fig. 2.

It can be seen from the simulation analysis results as shown in Table 5 and Fig. 2 that when the value is over-sized or too small, the PSO algorithm is only applicable to convergence of local optimal solution. Namely, when the governmental macroeconomic regulation and control are over-sized or too small, the path evolution of the industrial cluster is comparatively conserved and can only perform convergence of local optimal freedom degree. The cooperation lasting degree and localization factors are around 0.8 and 0.4. The difference between the two is 2:1. Namely, the final trend of the industrial cluster is concentrated to 17 and 20 of enterprises. And when the value w is moderate $w = 1$, namely, when the governmental macroeconomic regulation and control are appropriate, the industrial cluster location convergence will be at the optimal freedom degree. The cooperation lasting degree and localization factors are around 0.19 and 0.05. The ratio between the two is basically at 4 : 1. Therefore, namely, the final trend of the industrial cluster is concentrated to 5 and 12 of enterprises.

2. When w =1.0, and $c_1 = 1$, $c_2 = 5$ and $c_1 = 5$, $c_2 = 1$, namely, when cooperation degree c_2 is considerably higher than competition c_1, or vice versa, the simulation results are as shown in Table 6 and Fig. 3 below.

From the simulation results of Table 6 and Fig. 3, it can be seen that when the cooperation degree of enterprises is considerably higher than the competition degree, the path evolution of the industrial cluster is more conservative. If the enterprises are losing the competition between enterprises, the strategic decision freedom degree F cannot get the optimal value as well. The development tendency of the industrial cluster will always stay around the cooperation lasting degree and localization factor of 0.5–0.7 and 0.29. Namely, the last industrial cluster will develop to the mode of 6 and 13 enterprises.

Table 5

Increasing industrial cluster evolution convergence results

w	Convergence cooperation lasting degree and localization factor/(x, y)	Strategic decision freedom degree F/max$F$
0.3	(0.8235, 0.4265)	0.5915
0.5	(0.8236, 0.4254)	0.5914
1.0	(0.1984, 0.0540)	0.6137
1.5	(0.8028, 0.4734)	0.5824

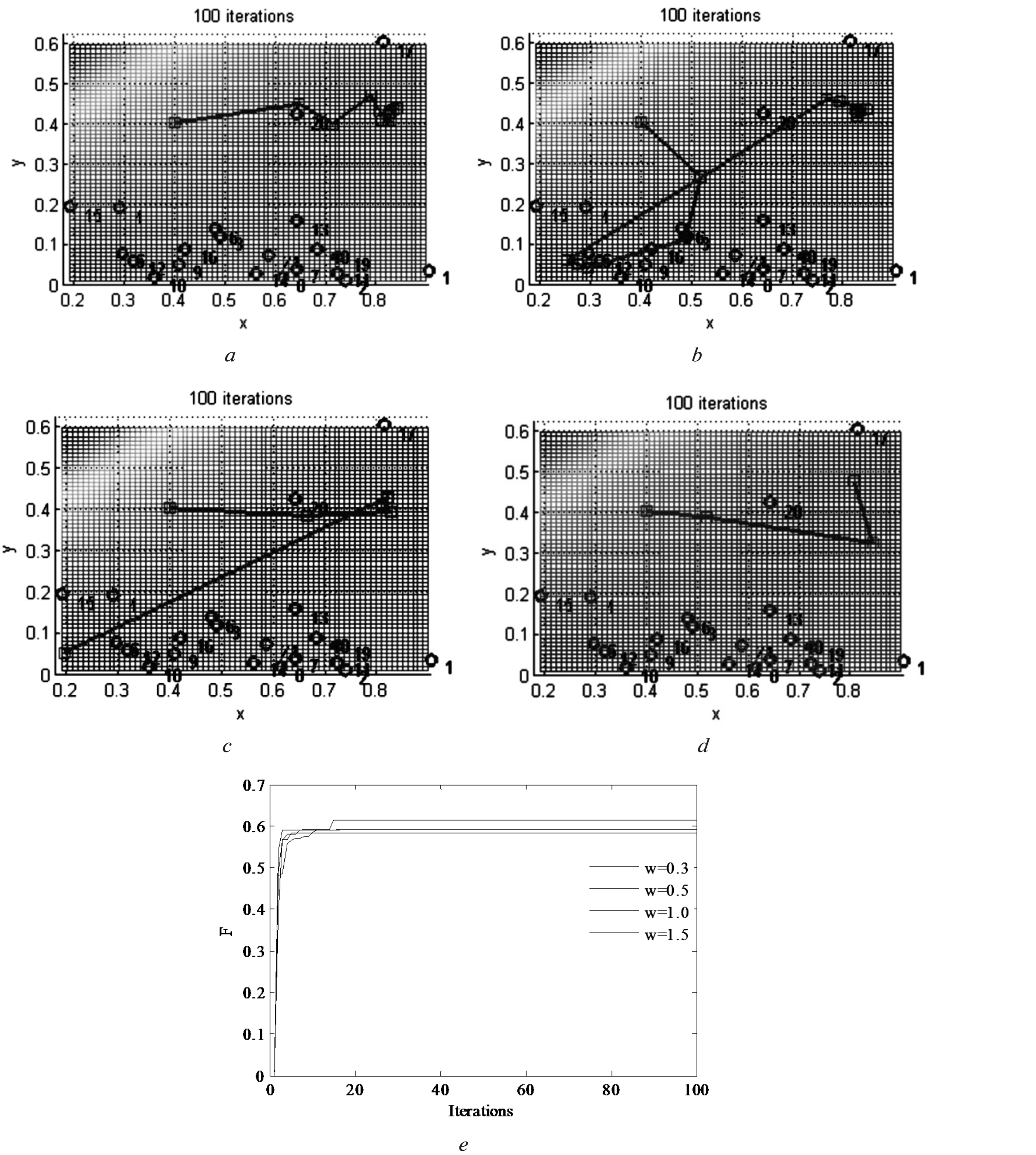


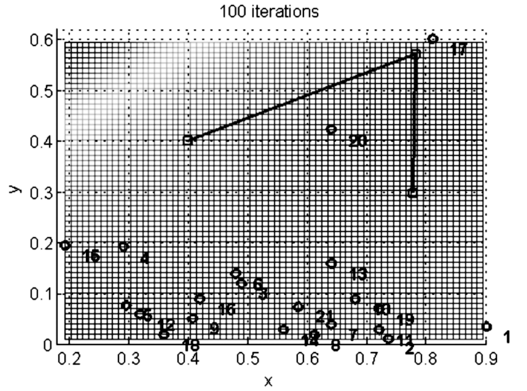
Fig. 2. Figures a, b, c, d — show industrial cluster variation diagram of different values ($w = 0.3$; $w = 0.5$; $w = 1.0$; $w = 1.5$); e — shows change results of enterprise strategic decision freedom degree F

Conclusions. First of all, the paper analyzed relevant concepts and practical implications of the industrial cluster, and deeply analyzed the effect of the industrial cluster innovation ability on enterprises. In addition, through summarizing the research achievements of the related industrial cluster at home and abroad, the paper analyzed the common characteristics between the industrial cluster and the PSO algorithm combining with self-organizing path dependence of the industrial cluster specific to the defects at

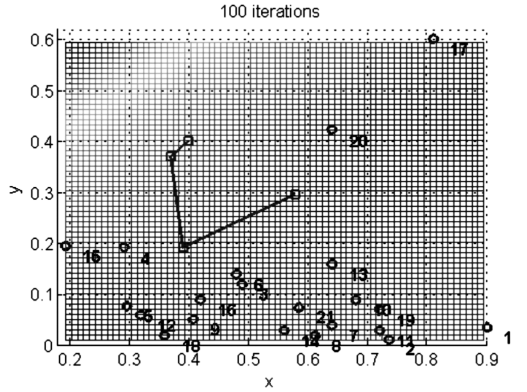
Table 6

Industrial cluster evolution convergence results at different degrees of cooperation/competition

c_1	c_2	Convergence cooperation lasting degree and localization factor/(x,y)	Strategic decision freedom degree F/max$F$
1	5	(0.7771, 0.2971)	0.5651
5	1	(0.5784, 0.2961)	0.5097



a



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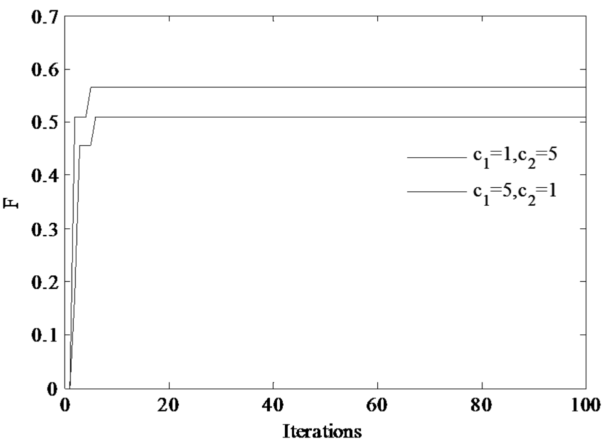

c

Fig. 3. The impact of cooperation/competition on industrial cluster evolution:

a and b – show industrial cluster variation at different cooperation/competition degree ($c_1 = 1$, $c_2 = 5$; $c_1 = 5$, $c_2 = 1$); c – shows variation result of strategic decision freedom degree F of the industrial cluster

generation process of the industrial cluster and evolution being at qualitative discussion stage. It proposed an industrial cluster evolution model based on the PSO algorithm by setting the industrial cluster evolution of Heilongjiang medicine industry as an example. It turned out that the PSO algorithm can be applied for quantitative and qualitative analysis of the evolvement rule of the industrial cluster. In addition, it can be seen from the case simulation results that with appropriate governmental macro regulation and control, as well as equilibrium state of competition and cooperation between enterprises, the eventual industrial cluster will mainly tend to be the enterprise model to maintain the existing market share and expand production. When the governmental macro regulation and control are over-sized or excessively small, or the competition and cooperation between enterprises are under non-equilibrium state, the final industrial cluster will tend to be the enterprise model to develop new products and new markets.

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Мета. На противагу існуючим недолікам промислових кластерних досліджень у країні і за кордоном, у роботі аналізується еволюційний процес, заснований на роєвому алгоритмі.

Методика. Був створений шаблон (форма) розвитку промислового кластера на основі залежності від попереднього стану в поєднанні з роєвим алгоритмом. Проведене імітаційне моделювання на шаблонному алгоритмі, запропонованому у статті.

Результати. Показали, що шаблон, представлений у роботі, може бути застосований для кількісного та якісного аналізу еволютивних правил промислового кластера. Крім того, з результатів

моделювання можна бачити, що при відповідному державному макрорегулюванні й контролі, а також рівноважному стані конкуренції та кооперації між підприємствами, промисловий кластер, що розвивається, буде, як правило, моделлю підприємства, що зберігає існуючу долю на ринку та розширює виробництво. Коли урядове макрорегулювання й контроль завищені або дуже малі, або конкуренція та кооперація між підприємствами знаходяться в нерівноважному стані, кінцевий промисловий кластер прагнутиме до моделі підприємства з розробкою нових продуктів і нових ринків.

Наукова новизна. У процесі вивчення еволюційного процесу промислового кластера, існуючі дослідження як і раніше залишаються якісним етапом обговорення для виробничого процесу та еволюційних правил промислового кластера. Дослідження не є досить глибокими й не дозволяють кількісно описати динамічні ефекти промислового кластера. Отже, робота встановлює зв'язок між роєвим алгоритмом і характеристиками промислового кластера, що самоорганізується. Об'єднання з теорією залежності від попереднього стану успішно промоделювало розвиток промислового кластера шляхом адаптації роєвого алгоритму.

Практична значимість. Результати імітаційного моделювання дозволяють ефективно проаналізувати еволюційний процес промислового кластера, якісно моделювати еволюцію характеристик і правил промислового кластера. Крім того, це може забезпечити новий якісний аналіз для академічних досліджень промислового кластера.

Ключові слова: *промисловий кластер, рій часток, закон еволюції, залежність від траєкторії*

Цель. В противовес существующим недостаткам промышленных кластерных исследований в стране и за рубежом, в работе анализируется эволюционный процесс, основанный на роевом алгоритме.

Методика. Был создан шаблон (форма) развития промышленного кластера на основе зависимости от предыдущего состояния в сочетании с роевым алгоритмом. Проведено имитационное моделирование на шаблонном алгоритме, предложенном в статье.

Результаты. Показали, что шаблон, представленный в работе, может быть применен для количественного и качественного анализа эволютивных правил промышленного кластера. Кроме того, из результатов моделирования можно видеть, что при соответствующем государственном макрорегулировании и контроле, а также равновесном состоянии конкуренции и кооперации между предприятиями, развивающийся промышленный кластер будет, как правило, моделью предприятия, сохраняющего существующую долю на рынке и расширяющего производство. Когда правительственное макрорегулирование и контроль завышены или слишком малы, или конкуренция и кооперация между предприятиями находятся в неравновесном состоянии, конечный промышленный кластер будет стремиться к модели предприятия с разработкой новых продуктов и новых рынков.

Научная новизна. В процессе изучения эволюционного процесса промышленного кластера, существующие исследования по-прежнему остаются качественным этапом обсуждения для производственного процесса и эволюционных правил промышленного кластера. Исследования не являются достаточно глубокими и не позволяют количественно описать динамические эффекты промышленного кластера. Следовательно, работа устанавливает связь между роевым алгоритмом и самоорганизующимися характеристиками промышленного кластера. Объединение с теорией зависимости от предыдущего состояния успешно промоделировало развитие промышленного кластера путем адаптации роевого алгоритма.

Практическая значимость. Результаты имитационного моделирования позволяют эффективно проанализировать эволюционный процесс промышленного кластера, качественно моделировать эволюцию характеристик и правил промышленного кластера. Кроме того, это может обеспечить новый качественный анализ для академических исследований промышленного кластера.

Ключевые слова: *промышленный кластер, рой частиц, закон эволюции, зависимость от траектории*

Рекомендовано до публікації докт. техн. наук В. В. Гнатушенком. Дата надходження рукопису 29.07.15.