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Entropy-Based Complexity Metrics for Coal Resource Consolidation System Engineering

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Abstract

Based on the basic principle of management entropy theory, this paper constructs a metric scale and entropy-based quantization model for evaluating the complexity of resource consolidation system engineering. Under the transformed structure of coal resource consolidation system of Shanxi Province and the constructed relation mode, the proposed model is put in practice to analyze and evaluate the complexity of Shanxi coal resources consolidation system. The results show that by importing material, energy and information, the complex system evolves to the direction of order and dynamic balance.

Keywords: complexity metrics; resource consolidation; information measurement; system engineering

1. Introduction

In China, coal resource has a strategic significance for the national economic and social development. For a long time, the traditional coal development patterns caused a series of problems, such as a large waste of resources, ecological environmental damages, and frequent accidents. To improve the effectiveness and efficiencies of utilizing the coal resource is urgently needed. One of the ways out of the dilemma contemporarily is to consolidate the coal resources to facilitate the industrial concentration and promote the sustainable and healthy development of the coal industry in China.

Many experts and scholars at home and abroad studied and discussed the problem of resource consolidation. Abroad, resources consolidation is carried on earlier. The nationalization of coal industry in British after World War II and the privatisation in the period of Margaret Thatcher are policies, which aimed to adapt the productivity level at that time, and promote the upgrading of the British coal industry. Since that, there are the nationalization of the British Commonwealth members, the nationalization of resources in the United States, Chile and other countries etc. For resources consolidation in China, the experts have different understandings from different angles. Some experts study resources consolidation from the view of industry structure, and believe that intensive development and large-scale production are the objective demand that accelerates development of the coal industry while unreasonable industrial

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structure has always been the major problem that influenced the development of coal industry in our country. The coal resources consolidation and M&A follow the gradual progress pattern of industry, accord with national policies for the coal industry, and enhance the sustainable development ability of coal industry, so the general strategic direction is completely correct.

Since the argument that the organization is open system began to spread in 1960s, the concept of complexity first appeared in organization theory. Complexity theory has become the important theoretical pillar of organizational science[1, 2] . Daft. Richard regards complexity as activities in the organization and the number of subsystems, and points out that it can be measured using three dimensions: vertical dimension is the number of middle level in the organization; horizontal dimension is the number of the projects which the organization must deal with at the same time; regional dimension is the number of space position[3]. These studies discuss complexity from the angle of the structure of organization system. For natural resource complexity management, literatures[4-6] have proposed new engineering models and techniques to handle the dynamic states and complicated relationships in nature. Meanwhile, we should notice that management objectives faced the 21 century of knowledge economy and information time will be more complicated. The complexity of management objectives in resources consolidation system engineering, the limitations of existing quantification theory and hierarchical understandings make various evaluations for complexity of resource consolidation organization. The research is still in the primary stage. For several years Song proposed the category of general (macro) and special (micro) management entropy theory using management entropy theory and method[7], and the basic idea of measuring complexity of organization management system utilizing entropy theory. This article explores and quantifies complexity of resource consolidation system from three dimensions: the management information, function and structure, measures management complexity of coal resource consolidation system using management entropy, and analyzes complexity of coal resource consolidation organization system in Shanxi province.

2. A method for measuring the management system of resource integration

The assessment domain of management system of resource integration is made of complexity of structure, complexity of function and complexity of information transformation, which is a multidimensional issue. Each dimension has three factors.

2.1. Definition of metric spaces

Define entropy to the different magnitudes of each dimension; we then get a complexity vector space termed *E*. It is content variables are *X, Y* and *Z*. The elements of *E* are defined as the complexity vector $e_i = (x_i, y_i, z_i)$.Here e_i represents a particular domain, and the three-dimensional metrics of the rate of information transformation, function and structure. Vector $e_i \in H^3$, here H^3 is three-dimensional space over H, H is set of the information entropy value.

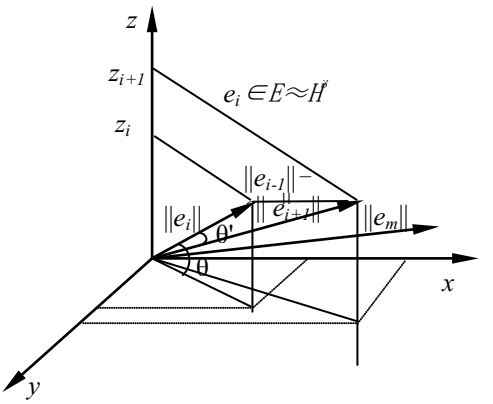

Fig.1. The vector space of complexity

Definition: the norm of the vector e_i over vector space E in H, $\|e_i\| : E \to H \cdot (E, \|e_i\|)$ is called the complexity vector space with inner product. $\|e_i\|, \|e_i - e_{i+1}\|$ is called the metric over *E*, represented in term *s* of the distance from e_i to e_{i+1}.

Defined by $d : \mathrm{E} \to \mathrm{H}$, and

$$d(e_i, e_{i+1}) = \sqrt{(x_i - x_{i+1})^2 + (y_i - y_{i+1})^2 + (z_i - z_{i+1})^2} \quad (1)$$

d is the quantity of information produced by department B_{i+1}, after department B_i.

2.2. The calculation of each metric complexity measurement

In order to calculate the complexity, Newton's work law has been used here:

$W = F \cdot D \cdot \cos\theta$

Here, W is the abstract 'effort' value; in reality though it is the informational content of entropy-complexity metric. $F = \|e_i\|$ is force applied across the distance D, θ is the vector angle formed by the application of force. Fig. 1 represents the components of a complexity vector in a particular vector space.

By the Euclidean triangular relation among vector components, we obtain

$$\cos\theta = \frac{\sqrt{\|e_i\|^2 - z_i^2}}{\|e_i\|} \quad (2)$$

Then, by substituting equation (2) in (1), the equation representing effect for department i in the specific space E can be obtained.

$$w_i = z_i \sqrt{\|e_i\|^2 - z_i^2} \quad (3)$$

The total information content needed to produce for the enterprise system is

$$\|B\|_e = \sum_{i=1}^{m} z_i \sqrt{\|e_i\|^2 - z_i^2} \quad (4)$$

2.3. Unified metric of total complexity measurement

E_x, E_y and E_z are the vectorial spaces of the rate of information transformation, function and structure in H^3 respectively. Here H^3 is a three-dimensional vectorial space. Considering the metric of the entire management organization complexity, the unified complexity space may be established as $E_x \times E_y \times E_z$. This is known as a three dimentional entropy space. Φ is a map defined by $\Phi : E_x \times E_y \times E_z \to H$. Φ is three-linear over H. If we define a 3×3 matrix B_e which consists of E_x, E_y and E_z over department B_i as the rows of the matrix, then $\|\Phi_i\| = \|\Phi(Ex_i, Ey_i, Ez_i)\| = |\det(B_{m_i})|$ is the tensorial norm, to represent the unified entropy of the department B_i. Φ_i is information content volume.

Set of $(T_3(H), \|\Phi_i\|)$ is called complexity multi-linear space. From the norm $\|\Phi\|$, the distance from E_i to E_{i-1} can be defined as:

$$\|\Phi(Ex_i, Ey_i, Ez_i) - \Phi(Ex_{i-1}, Ey_{i-1}, Ez_{i-1})\| = |\det(B_{m_i} - B_{m_{i-1}})| \quad (5)$$

This is the total information content produced by department B_i, after department B_{i-1} from management information flow. Then the equation

$$\|B\|_r = \sum_{i=1}^{m} \|\Phi_i\| = \sum_{i=1}^{m} \|\Phi(Ex_i, Ey_i, Ez_i)\| = \sum_{i=1}^{m} |\det(B_{m_i})| \quad (6)$$

is the total tensor entropy volume, and

is the total tensor entropy volume, and

$$\|B\|_E = \sum_{i=1}^{m} \left\|\Phi(Ex_i, Ey_i, Ez_i) - \Phi(Ex_{i-1}, Ey_{i-1}, Ez_{i-1})\right\| = \sum_{i=1}^{m} \left|\det(B_{m_i} - B_{m_{i-1}})\right|$$

(7)

is the total information entropy content needed to produce this organizational system B. These metrics are termed as the unified management complexity.

3. Empirical Research on Coal Resource Consolidation in Shanxi

Shanxi has made great contributions to integrated management of mineral resources, resource and energy safety, and sustainable development of national economy. Shanxi Provincial Party Committee and the Shanxi Provincial People's Government carry on the thorough deployment to the coal resource consolidation, and the elaborate planning and designing of structure, mechanism, procedure, human resource, and interior and exterior environment.

3.1. Analysis of the structure of system and description of figures

The organization system of the coal resource consolidation is created, which is made up of Shanxi Development & Reform Commission, State-owned Assets Supervision and Administration Commission, Land and Resources Bureau, province coal inspect bureau, departments of environmental protection, assessment, financing, and law, seven coal groups as the main body of integration, China National Coal Group Corp, Government of each city and county, and other relevant departments led by secretary of the Provincial Committee and the Governor and the Coal industry. The organizational structure and the mechanism are complex, while is the top layer is the top leadership, and the bottom layer is more than 60 governments, which participating in consolidating coal resource. There are five levels of management in the system. Fig.2 is the system structure of organization management system of coal resource consolidation in Shanxi.

According to the theory and methods mentioned above, the complexity of organization management system of coal resource consolidation is evaluated.

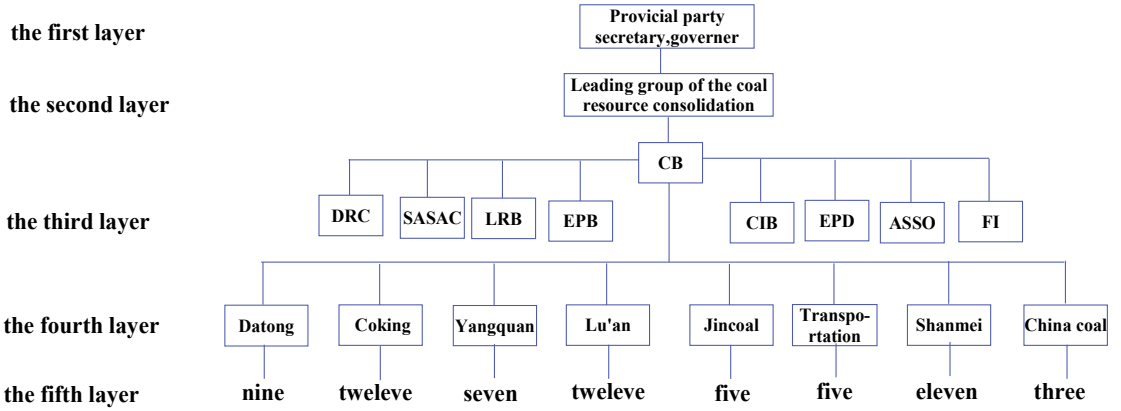

Fig.2. The organization management system of Shanxi CRS

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According to the basic meaning of information entropy, the contribution of each basic evaluating unit to the relative whole factor with respect to average information content is calculated. The basic factors are

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According to the basic meaning of information entropy, the contribution of each basic evaluating unit to the relative whole factor with respect to average information content is calculated. The basic factors are loops, arcs and nodes, which comprise the organizational systems. The arc is defined as a cause-effect chain.

Supposing that n presents the causality chains of organization. $\Phi(a)=n$， r is the unlimber of causality chain of single evaluating unit, t is number of causality chain of different evaluating unit, then

$$n = \sum_{r=1}^{t} n_r \tag{8}$$

If the relative frequency is $fr=n_r/n$, according to the relation between f_r and its probability p_r, entropy can be defined as follows:

$$H = -\sum_{r=1}^{t} \frac{n_r}{n} \log \frac{n_r}{n} = -\sum_{i=1}^{t} p_r \log p_r \tag{9}$$

Similarly, by simplifying the descriptions of analyzing other evaluating factor, the value forms for each evaluating factor is built, as in the Tab.1, Tab.2, and Tab.3.

The value of each evaluating factor should be analyzed connected to management operation mechanism of study object. This case takes organization and operating mechanism of the company as research subject.

Tab.1 Complexity metric of information transformation

Dep	*Xx*	*type*	*Xy*	*Xz*	*H(Xx)i*	*Exi* *Xdi*	*Eyi* *H(Xy)*	*Ezi* *H(Xz)*	*Ex*
M1	1	star	8	1	0.0233	0.0233	0.0973	0.0085	0.1004
M2	1	star	8	2	0.0233	0.0466	0.0973	0.0149	0.1089
M3	16	star	8	3	0.1385	0.1851	0.0973	0.0205	0.2101
M4	64	chain	16	64	0.0840	0.2691	0.1372	0.1448	0.3350
M5	0	chain	44	220	0	0.2691	0.1471	0.0910	0.3199
Total	82		84	290					1.0743

Tab.2 Complexity metric of function

Dep	*Yx*	*Yy*	*Yzi* *1 2 3 4 5 6*	*H(Yx)i*	*Exi* *Ydi*	*Eyi* *H(Yy)*	*Ezi* *H(Yzi)*	*‖Ey‖*
M1	0	3	1 1 1	0	0	0.028	0.0800	0.0848
M2	1	5	1 1 1 1 1	0.0104	0.0104	0.0409	0.3240	0.3267
M3	2	5	1 1 1 1 1	0.0181	0.0285	0.0409	0.3240	0.3278
M4	48	49	16 8 8 8 15	0.1427	0.1712	0.1509	0.5685	0.6126
M5	176	132	44 44 44 44	0.0857	0.2569	0.1138	0.3228	0.4280
Total	227	194	62 54 3 53 55 17					1.7799

Tab.3 Complexity metric of structure

Dep	*Zx*	*Zy*	*Zzi* *1 2 3 4 5 6*	*H(Zx)i*	*Exi* *Zdi*	*Eyi* *H(Zy)*	*Ezi* *H(Zzi)*	*‖Ez‖*
M1	1	1	1	0.0085	0.0085	0.0091	0.0697	0.0708
M2	2	1	1 1	0.0149	0.02344	0.0091	0.0986	0.1017
M3	3	1	16 1 0	0.0250	0.0439	0.0091	0.0744	0.0869
M4	64	64	64 16 16 240	0.1448	0.1887	0.1487	0.5483	0.5986

M5	220	0	44 44 370	0.0910	0.2797	0	0.3362	0.4373
Total	290	67	82 62 60 610					1.2953

3.3. Analysis of the structure of system and description of figures

The unified metric of management complexity for organization management system of resource integration can be obtained by the equation (5), (6) and (7), and determinates the three-dimension vector space for each structural hierarchy as follows:

Tab.4 The unified complexity of organization system of resource consolidation

	Layers	$\lvert\det(B_{m_i})\rvert$	$\lvert\det(B_{m_i} - B_{m_{i-1}})\rvert$
$\lVert B\rVert_T$ =0.0116， $\lVert B\rVert_E$ =0.0018 is the united complexity value.	m1	0.0009	
	m2	0.0007	0.0007
	m3	0.0012	0
	m4	0.0009	0.0007
	m5	0.0080	0.0004
		$\lVert B\rVert_T$ = 0.0116	$\lVert B\rVert_E$ =0.0018

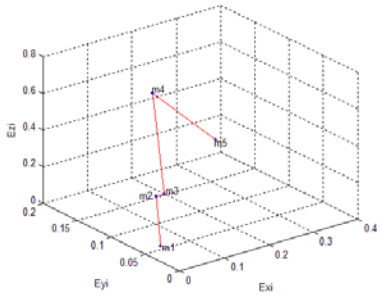

Fig.3. Evolution of function complexity

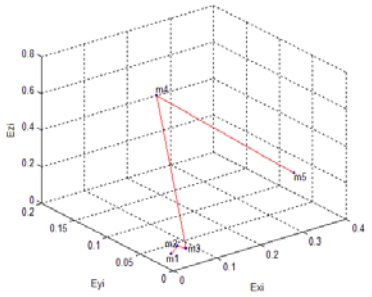

Fig.4. Evolution of structure complexity

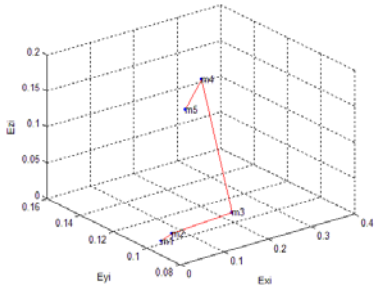

Fig.5. Evolution of complexity of information transformation

The chaotic situation of mining and energy development in the early stages of coal resource consolidation in Shanxi is actually an external imagery that the complex system is in disorder, while the management entropy is increasing and the administrative efficiency is decreasing. Through coal resource consolidation and reorganization of enterprises, industrial concentration is improving, resource waste is

reducing, the ecological environment is protected, and the incidence of accidents is reducing. So the management dissipative structure and the administrative efficiency are increasing. The coal resource consolidation in Shanxi makes the complex system evolve to the direction of order and dynamic balance by importing material, energy and information into the disordered exhausted system, which is far from equilibrium.

4. Conclusion

The domination principle of social system development requires that the successful social activity of human beings follows that the entropy and complexity of controlled objects is reduced and order degree is enhanced. The complexity theory of organization management is a methodology in management science, which can be used in increasing efficiency of management system. Actually, the optimal design of organization system of resource integration is to optimize the system's structure and reduce complexity of constructs and entropy. The management complexity of resource consolidation is analyzed and quantitative in this paper based on the management entropy. The information content of organization system of coal resource integration is measured.

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