Innovation Complexity in the Dynamic Development of an Enterprise:

Case Study of the Innovation Marvel of the Shandong Mine Area

Hua-ling Song, Jin-ke Li , Guo-feng Wen , Hong-yan Li
songhl@ccec.edu.cn
Shandong Institute of Business and Technology, Shandong Yantai 264005, China.

Abstract

The purpose of this paper is to establish the methodology of complexity assessment for the innovation system, named as conception system. The article applies the theories and methods of mathematics, dynamics, information science, charting theories, relational mathematics, etc, to put forth the concepts, definitions, basic theorems and mathematical models of the information force, energy and structural complexity measure. Based on the basic theories of management entropy, it establishes a new set of the vectorial space, mathematical models of metric for assessing the innovation systems structural complexity, and proposes theorems of simplification and complexity decrease for innovation systems., The author utilizes the dynamic analyzing method as a case study; applies the complexity methodology to analyzing the dynamic causality of Shandong Company's innovation and development courses; studies the perceptional complexity of the subsystems of the innovation system, such as conception, management, technology (which are non-structural and conceptual complexity systems), and mine development, production, technology, equipment, and working organization systems (which are structural complexity system known as technology complexity). Hopefully, the article attempts to decode the mystery of Shandong Company's innovation marvel and explain the true essence of modernization enterprise's jumping development.

Keywords

Enterprise, management, and technology innovation; feedback loops; information entropy; structure based-complexity theory

Innovation Complexity in the Dynamic Development of an Enterprise

Introduction

A theory of innovation was put forth by the economist Alois Schumpeter in 1912 which emphasized a new integration of the elements of production. Recently, complexity theory has supplied a revised basis for theories of innovation which has led to much rethinking of the key components necessary for innovation (Kurtyka, 1999: 24).

Enterprise innovation is the result of mutual actions among various individuals and elements of the market (CAO, 2004:24). The innovative management of enterprise includes the development of technology, products, culture, and management innovations within the context of a complex system (LI, 2000:24). Zhang (2002: 24) states, "the enterprise innovation system is a compounded and organic wholeness; the innovation process is dynamic, integrated, synthetic; information and chaos theories help in understanding the evolving process of innovative systems" (Kurtyka, 1999, 24). Similarly, Elizabeth (2005: 24) describes a dynamic and complex feature of innovative systems. Based on observing the evolving history of innovative systems, Wei (2004, p.24) attempts to reveal the particular internal structures involved, the elements connecting patterns across the system, and to construct a framework that can normalize the complexity of innovative systems.

The authors had previously put forth theories and methodologies to assess the complexity of enterprise (Song, 1999, 2000, 2001, 2003, 2004:24). Using the "dynamic analyzing method" (JIA, 2002:24) in this paper, the authors apply a complexity methodology to analyze the dynamic causality of Shandong Company 's innovation and development courses, study the complexity of the subsystems involved, in general to attempt to decode the mystery of Shangdong Company's great success, and in the process aid in the understanding of the precipitous modernization of an enterprise.

Leaps of Innovation in the Development of the Shandong Company

The Shandong Company is located on a barren plateau in the Shenmu County of the Shaanxi province in the People's Republic of China. This mining enterprise operates in the largest coal field of China, which is 31,172 square kilometers in area and contains an estimated 223.6 billion tons of coal in explored reserves. It is also a very modernized mine - by world standards - and has achieved a number of milestones in the world mining industry. Among them are three significant achievements made by the Daliuta drift mine subsidiary, as follows:

- Achieving output of 10.94 million tons of saleable coal by one shaft and one working face in 2002. That is the highest productive capacity of any similar mines in the world;
- Attaining an annual production level of 8 million tons with a comprehensive working face. It ranks the top of the world's list of comprehensive mining productions;
- The production efficiency per mine worker reached 114 tons in 2002.

In addition, six other world records were achieved:

- The mine field's annual increment of 10 million tons gives it the fastest growth speed in the world;
- Yujialiang mine, one of the subsidiaries of Shandong Company, built its new mine and achieved 8 million ton output yearly within nine months, making it the fastest shaft building speed in the world;
- The funds required to establish Yujialiang mine were only USD 6.01 per ton, representing the lowest investment rate in the coal mining world;
- Five main mines in the previously-mentioned mining field all adopted automatic controlling techniques; the advanced levels of these mines were ranked at first place in the world mining industry;
- The death rate for each million tons of production is 0.026, which is the lowest death rate in the world mining industry;
- Further, the efficiency of all staff reached 70 tons per person for the Shandong Company in 2002, which is also one of best productivity rates in the world (Liu, 2002; Wang, 2002; Yang, 2002:24).

The question that naturally arises is how the Shandong Company created such almost miraculous results. Innovations! They are the result of integrating technological innovation with management innovation. These innovations represent a movement a stable equilibrium state to an unstable equilibrium state, even a chaotic state, through further development and evolution to reach a high-level dynamic equilibrium state, and then, ultimately towards a new point of transformation. It is hoped that to research the developing course of this enterprise and discover its mechanisms of evolution will move forward the research and practice of complexity theory applied to innovation (LIU, 2002: 24).

A Complexity Analysis of the Shandong Company

Innovation Feedback Loops

The developing and evolving course of Shandong Company's innovation is an evolving process of complexity since a mine system is a complex system. Regarding the system's structure, there are many subsystems with multi-layers, factors, variables, complicated relationships, and changing states (such as stable, equilibrium, non-equilibrium, chaotic states). They emerge from the complexity characteristics of recursion and non-linearity, dynamical systems, entropy, coupling, diffusion, dissipation, forking, coordination, self-organization, and self-adaptation. These features show themselves in uncertainty features, including "fuzziness" as in "fuzzy sets", randomness and even "fuzzy-randomness", so that the course of innovation takes on the dynamical features of complex systems. The analysis and evaluation of the role of complexity in the evolution of the mining system at Shandong shows the presence of feedback loops which intensify, and disturb each of the factors, in effect, determining a "virtuous circle" shown in Figure 1:

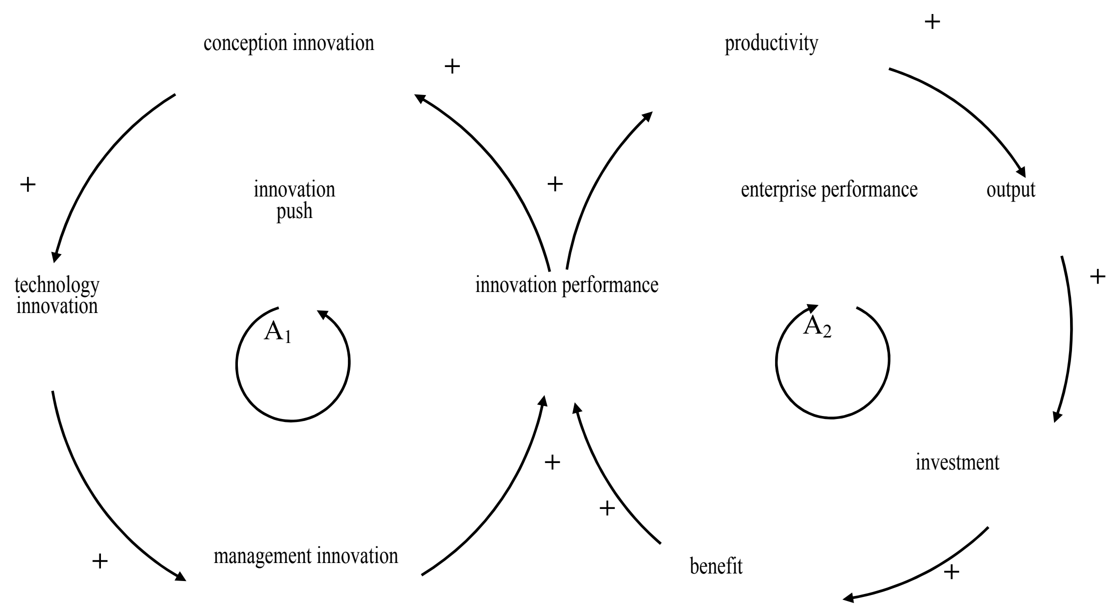

Figure 1: Innovation performance feedback loop

Concepual Innovation and Management

As shown in Figure 1 the set of factors involved in the innovation at the Shandong mining enterprise consists of conceptions, management, technological pathways, the technology itself, and so on. According to The Law of Universal Priors, one of twenty laws of structure-based complexity theory (Warfield, 1999: 24) we analyze the priority of these innovation elements: conception dominates action and as such has priority over the other elements of the innovation set. A revolutionary conception is the core of Shandong Company's enterprise culture. We have found that only if the primary conceptions change, do the other elements change. These conceptional innovations integrate resources (human, informational, time, materials, financial, and technological), management, performance, work runs, as well as safety considerations. In addition, the primary conception means that the subsystems develop in harmony, including that between the main industry with auxiliary ones, the enterprise with its environment. Also, the company takes advantage of outside technological resources, and establishes a alliance with other enterprises.

The most essential processes include: substitute the highly diffused but centralized management with a systematically integrated management structure to form the basis for a systematic integration of the subsystems of the organization; systematically integrate production operation processes that combine system optimizations with equipment modernization; and to develop and apply advanced computer information networks and scaled management software systems.

A Resource Enterprise

Because the Shandong Company is a resource enterprise, its competitive ability is mainly decided by the production cost of its products. The strategy of "cost lead" therefore becomes the development strategy of a resource enterprise. From pursuing throughput increases to emphasizing quality upgrade, Shandong Company intensifies the qualitative, cost efficiency to achieve stable output with low production costs. From diffused, small scale, low level and low efficiency production to scientifically determined and scaled-up running of production process, the company emphasizes self-development among all the units.

Shandong Company describes its operation as a "five-high" development strategy: "high start-point, high science and technology, high efficiency, high effectiveness, and high quality." This initial conception causes a series of changes in how management is conceived, how performance must connect with management, and how science and technology, efficiency, and quality are to act as guiding points.

Furthermore, the Shandong Company places safety as a first priority, beyond everything else, a "holism safety" conception framed by human engineering factors. Safety is a number one consideration: the death rate for each million tons of production is 0.026, which is the lowest mining industry rate in the world from 1999 to 2003!

The company begins with importing advanced technology equipment and then carries out a gradual matching with existing technology. This is a dynamic, complex conceptual system. Its complexity causality figure is as follows:

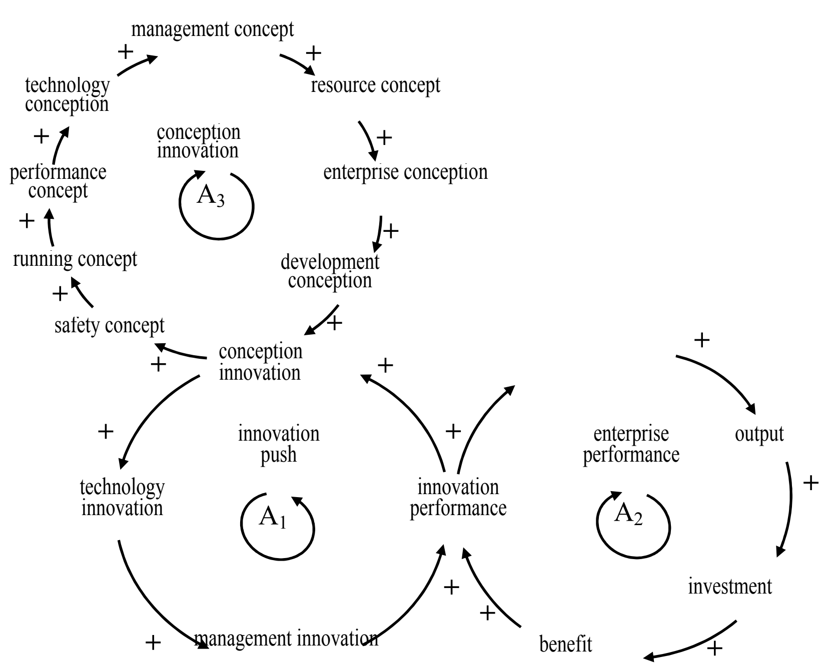

Figure 2: The conception innovation feedback loop

Technology Innovation

The excellent natural conditions of the Shandong mining area support a broad choice of mining technologies. Hence, deciding on the specific technology for the company became a key strategy. This was a very complicated decision comprising the following four crucial problems:

First, should the mining development model be one of opencast or tunnel development? One leading conception is that opencast development is more advanced than tunnel modeling. The main reason for that is the mining scale. Also, the efficiency of the tunneling model has been constrained by technology, equipment and transporting capacity under the "stripping ratio." But proven by practice, the opencast model is inefficient even when the stripping ratio reached 3:1 in 2000, and 2:1 in 2001. Therefore, the tunneling development model was eventually adopted.

Second, how to choose equipment, import or use ones endemic in the country? The imported equipment is good in quality, capacity and durability, but its price is high. Home grown equipment has a low price but its quality is poor, the capacity is relatively low, and it frequently needs maintenance. However, a leading concept was to support the national industry and accordingly utilize democratic equipment as much as possible at that time.

Third, how to choose the excavating technology, i.e., use the drifting machines or continuous coal-winning machines? Using a complex cutting machine is a mature excavating technology used in rock tunneling, but a continuous one is the coal headings excavation. The former needs the tunnel layout in the rock, the excavating speed is very low, high cost, and no permanent supports (e.g., no coal pillars). The second choice achieves high heading speed and more efficiency, uses a simple tunnel layout, and is low cost, but when the permanent support and coal pillar are needed, the winning rate is low. The leading conception is to utilize a comprehensive cutting machine.

Fourth, how to choose the auxiliary transport, wheel or rail mounted transport equipment? The traditional auxiliary transport model uses rail mounted transport equipment. It has more links, low speed of excavation, large work tasks for managing and maintenance, more staffing (accounted for 1 third of team), plus a high cost of conveying. Yet it is a mature technology for excavating transport. Wheel transport is a brand new auxiliary convey method with high speed and low cost. It is good for long distant transporting, and requires less maintenance and fewer staffing and links. Because it has never been used in a domestic mine (there are no domestic products in domestic use), thus its maintenance and parts become a problem. Therefore, the leading option was rail mounted transport equipment at that time.

The above four problems seem to be concrete problems about technology options, but, in fact, it is a choice between absorbing the new technology and seeking technology innovation boldly, or following the old track conservatively. According to the mainstream belief at that time, the company should just follow and copy the domestic production and running models and working technologies, with few or no innovations. Otherwise, it would have to innovate completely, and the innovation would have to be a structural innovation based on technology integration. That would mean fundamental changes in the production and technology and the operation organization model in the Chinese mining industry.This is a risk with no successful precedents.

According to the theory of Alexander Gershenkron, the enterprises of less developed nations can attain a speed of development that is much faster than that of developed nations. Likewise, the decision-makers of Shandong Company had foreseen they would have to withstand a world review of their enterprise production and their running model of technology, and would have to step into the advanced rank of world mining industry. It established the '5 high' construction policy, that is, high start point, high technology, high quality, high efficiency, high effectiveness in 1995. So Shandong made the astonishing decisions to choose the tunneling development model, the most advanced mining equipment from the world's first rank mining equipment companies, the high efficient and effective continuous coal-winning machines for excavation and the wheel convey cars for transporting.

Proven by practice, these were the correct options, and conformed with the the "advantage of backwardness of nations". In this way, the company realized leaps of development, created the highest efficiency level in the world mining industry, and achieved the dream of exceeding the world advanced level.

Innovation in Production Technology

Production technology innovation includes two aspects. One is innovation of the production technology method, accomplished by renewing and improving the technology equipment and parts. The other one is technology innovation of the production working process. The ability and advantage of production innovation for coal enterprises mainly concentrate on the production technology process. The innovation of production technology means relying on outside technological resources. This means that the technology equipment of subsystems, such as excavation, transportation, ventilation, draining, dust proofing, safety, all mainly rely on outside technologies. Additionally, the production equipment is provided by different suppliers, which also means the company needs to integrate and match different outside technological resources.

Integration innovation can be conducted either in the existing formal framework or in a new one. But the innovation of the technology framework is carried out on the basis to either keep the formal ones or change them. If the framework innovation goes with integration innovation, this kind of innovation is known as framework innovation based on technology integration. Concretely, this innovation process aims to take advantage of the enterprises' existing outside and inside elements and framework technologies resources to form a new technology framework.

On the other hand, coal production is an underground work, and the natural geological conditions are changeable. It is impossible for new technologies and equipment to be suitable for geological conditions completely, and they need to be modified and improved gradually. Thus, the technology innovation of coal enterprises is a time-consuming and gradual process. Even if the basic innovation activities have finished, the importing of new equipment can meet the new problems need to improve even further. This mainly presents the improvement of equipment fittings—parts innovation, aimed at enhancing the operating efficiency and ability of the whole production system. Meanwhile, this must include consolidating the results of innovation and perfecting them. This innovation is on the same level with formal innovation.

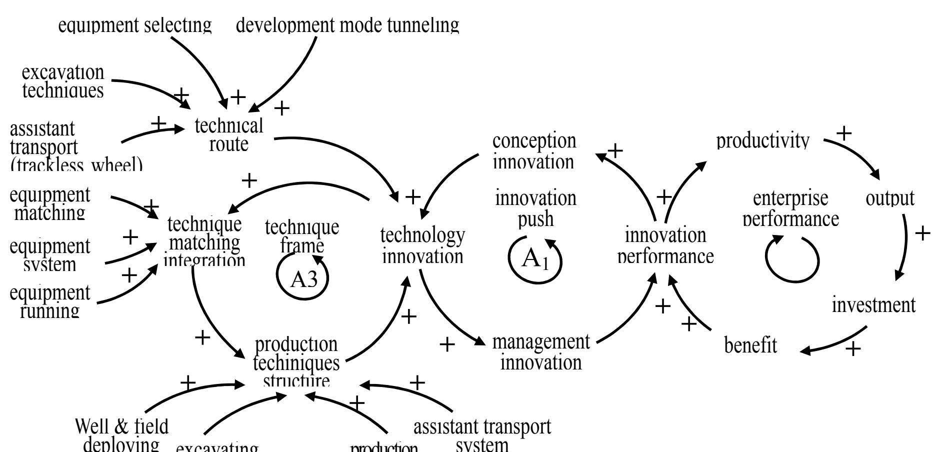

Figure 3. The technology innovation complexity analysis

The frame innovation based on technology innovation is Shandong Company's technology innovation route. It includes equipment matching integration and production system reformation. For the sake of realizing these innovations, they carry out a series of innovations in organization and management as well.

Integration of new with existing technology is a process of evolution and innovation including two aspects. First, to ensure the various machines operate smoothly and fully by applying multi-technologies and knowledge and taking the appropriate means. Second, supplying the necessary technological support for the equipment operating systems, including maintenance, repair, fittings supply, and ensuring the system is running at reliable and high efficient states.

After considerate thinking and studying of the conditions of the Shandong Company and world mining technologies and experiences, the CEOs of Shandong Company put forth the five-high policies of mine arena construction. They decided that the whole equipment used by mining systems should be the most advantaged in technology, best in features, strongest in capacity in the world mining technology.

Moreover, they achieved the equipment matching and integration by the following means. One is by operating the maximum test. This test takes advantage of holidays or days off for festivals, which can rule out the various disturbances from the internal enterprise completely. The departments at each level of the enterprise also stop other tasks to support the test which creates man-made and ideal equipment operation environments. Second, according to the results of the test, the improving schemes have been made to optimize and upgrade the systems' technology and organization. That means to ask the equipment suppliers to redesign the existing machines, and to upgrade. That way, the modern mining technology and equipment of the world can be integrated in the mining system timely, and the system can be kept at optimum at all the times. Third, taking advantage of information technology, the supervisor and monitors enhanced the coordination and integration levels for various machines, thus practically achieving mine synthetic automation.

The innovations of production technology systems and organization management are key factors which Shandong Company carries out by following these aspects:

- Innovating the mine field layout model completely and simplifying the production systems;
- According to the coal seams conditions, the mine adopts the tunnel opencast. Band layout, multi-working face or unilateral working face, and lengthening the working face from 500m to 6000—7000m are innovations in the mine layout;
- Innovating the technology of winnowing and tunneling;
- Adopting the advanced continuous mining machine and comprehensive tunneling machine; utilizing the advancing retreats that win and excavate simultaneously, and improving the practice gradually; using the double-wing winning technology with continuous mining system and self-propelled hydro-support; enhancing the efficiency

and extraction rate of coal winning and excavating further, especially the continuous coal mining machine which can make productivity grow double; and attaining the maximum economic efficiency;

- Innovating the auxiliary transport system;
- Adopting the most advanced auxiliary transport of the world; changing the auxiliary transport vehicle form traditional railway model to rubber wheel vehicle; using double headings with big sections; increasing the auxiliary transport speed greatly; decreasing the conveying time of staff, martial, equipment, etc.; and lowering the maintenance working volume of auxiliary transport systems;
- Innovating the production organizing patterns;
- In order to make the best use of the advantages of first-class outfits and production technology, the Shandong Company reforms the production operating and organizing patterns completely, and changes the three shift working and one shift preparing in one day to working 22 hours and maintaining 2 hours in 24 hours(that is the so called '8772' working system). In this way, the checking and repairing shifts have been canceled. The checking time is mainly concentrated on the stop time of the winning machine to ensure effective working time;
- Innovating the production organization pattern and intensifying the system's reliability and stability.

The reliability and stability of machinery and equipment became the dominant factors to contain production efficiency. Based on practice, the company has gradually formed the management model of production operation led by machinery management. The dynamic monitoring of the outfit operation has been realized and the accident rate (or failure rate) has been decreased to the lowest levels.

The Concept of Integration Management

Integration management is a new managing concept and method. Its core is to utilize the thought and conception of integration to direct the management practices of the enterprise, to optimize the various resources and elements in all respects, to activate the fusion and enlargement actions among to the units' advantage, and finally, to enhance the effectiveness and efficiency of all management activities.

Shandong Company can create the highest efficiency level in the world. The most essential ways to achieve that are: to substitute the highly diffused managing model centralized by production mine for a systematically integrated management model; to form the systematic integration of the transaction organization; to form the systematic integration of the production operation process combined system optimizations with equipment modernization; and to realize the whole enterprise running management integration by developing and applying the advanced computer information network and scaled managing software systems.

The Shandong Company put forth the management model of "three lines" in 1991. The three lines were manifested by a production line, an auxiliary production line and a service line. According to these three lines' contents, a completely internal "market" mechanism had been established gradually. It has pushed the main production line separate from community service. This management model lessened the load on the enterprise greatly and created the conditions for realizing the goal of mine production construction with high efficiency.

But, after many years of practice in modifying and optimizing the "three lines" management model, the company established developed the "four lines" model. This is a new management model for the Chinese mining industry. These "four lines"are as follows. First, the company centralized the common auxiliary and service businesses. This aspect of integrated management is known as systematic integration of business organizations or integration of enterprise organization systems. Second, based on the integration of equipment and technology matching, the company used the computer network, optimized the production systems, and gathered the scattered management points together to conduct the integrating and uniting of management. In this way, the many links coordinating works and staff in between were reduced in number, and the central institutes controlled each subsystem. This aspect of integration management is known as system integration of production operating processes.

Third, based on the above-mentioned two management integrations, the company conducted the development and application of advanced computer information network systems and scaled managing software in order to realize the integration management for all enterprise operations. Fourth, the above three aspects of integration management represent *intra*-enterprise integration. Besides these, the company also integrated its external resources, and realized the systematic integration of outside intellectual and technological capital. That is the so-called *inter*-enterprise integration.

Innovation of Human Resources Management

Under the lead of the company's entire strategy and policy, the basic innovation conceptions and policies for human resources managed were formed in a short period of time. The company recognized that its human resources were the core of all of its resources. Only if the company had adequate human resources conditions, could the natural and technological resources of the enterprise realize their true value. In other words, only if the company had a first-class staff could a first-class enterprise be created.

The realization of a high quality human resource management component consisted of:

- Cost conception: human costs are a critical part of coal cost; it is also the controllable and flexible costs in the overall production cost. The staff of Shandong Company has the strong conceptions of cost, checking, staffing employees strictly, and trying to realize an effective control of human resources costs;

- Resource conception : same as the natural resource, the human resources are the developing, regenerative and internal resources of enterprise. Only if the company develops and utilizes them properly, can the values of humans be truly embodied;

- Dynamic conception: the outstanding features of human resources are its "kinetic energy". The working enthusiasm and high cohesion of staff became the great push force in the development of Shandong Company;
- Market conception: Shandong Company grows with the market economic system of China. The market conception has been permitted each aspect of the production and running of the company;
- The united labor markets of China and the world are being formed gradually. Standing on the cutting edge of the market, Shandong Company manages and develops the human resources by the market conception;
- e. Virtual conception : human resource management has broken the closeness and limitation of traditional labor and personnel management, and prolonged the scope of the domestic and overseas markets. The company intensifies the construction and management of human resources. Meanwhile, it makes the best use of outside human resources, and utilizes virtual conception to fully integrate the human resources;

The organizational structure form of the enterprise is the base of production and operation, and also the base of human resources management. The innovations of Shandong Company begin with the aspects of production, operation and management organization, streamlining, optimizing and integrating its human resources.

a. Production Organization:

The production organization carries a series of staffing and managing problems in the processes of production, such as working regulations, arrangements, shifting groups, and operating organization, etc. When designing the staffing of the organization, the company makes the best use of the technological and scientific resources. Innovations in this aspect include merging the formal independent mines and regrouping the units of the internal mine. In this way, the company streamlines the organization, simplifies and merges the functions, and optimizes the working flow so that itruns effectively, efficiently and at a low cost.

b. Managing Organizations

The company integrates all administrative departments, adopts the conception of 'big functional departments', realizes the flat and flexible structures of organizations, and embodies the advanced conception of organization design of 'one transaction, one position; one position, one staff; one responsibility, one person; one person, multi functions'.

c. Operation Organization

As mentioned above, the Shandong mine started with the 'three lines management' and then with the reforms and innovations going very deep, the company created the management pattern of the 'four line' to smooth all its organizations, structures of staff and human resources more reasonably:

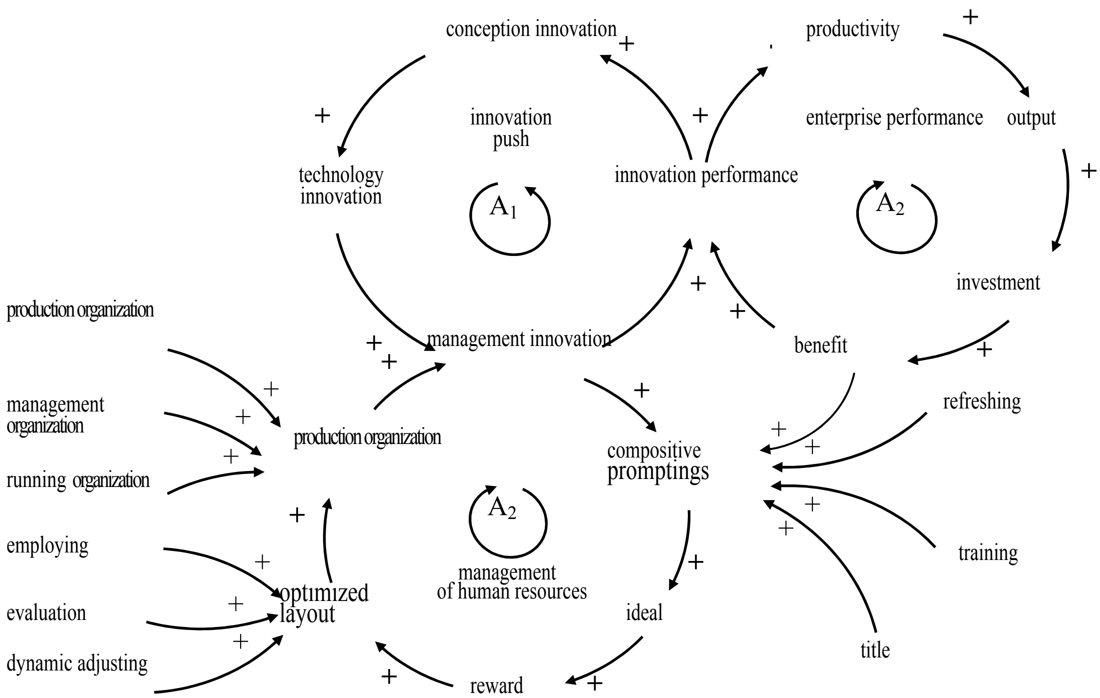

Figure 4. The human resource innovation push loop

The construction of enterprise employment includes staff employment, process evaluation and dynamic adjustment. Under the post designing principles of downsizing and efficiency, the company's staff complies with 'one transaction one post, multi-work one staff, one person all responsibility'. Under process evaluation, the company adopts many ways of analyzing and evaluating the various types of employees, such as through merit systems, indirect performance examination, work reports, interviews, democratic surveys, and so on. Under dynamic adjustment and in order to intensify the competitive conception and promote the working and learning activities and initiatives of employees, the company tries to retain certain activities of work positions and carries out a system of staff redeployment, adjustment for unqualified cadres, dismissal for ranking last, post rotation, etc.

In addition, the company tries to build up learning in the organization, trains and cultivates its employees regularly and fully, and supports adequate working forces to fulfill the needs of development.

The creativity of human beings is seen in their ability to produce new actions or behavioral patterns. The company pays attention to creating excellent working and life conditions for the staff, establishes good usage and stimulation mechanisms, combines personal development with enterprise development, simulates the staff's working enthusiasm and innovation passion and lets them take part in innovation actively, and thus finally attains unprecedented achievements.

A Key Outcome of Innovation: Excellent Performance

The implementation of innovation has performed very well. In the following tables we have listed other mining companies, such as Yanzhou, Datong, and Luan, etc. in China and made a comparison among their efficiencies.

Table 1 The main efficiency indexes of Shandong Company

	Unit	1997	1998	1999	2000	2001	2002
Output	10000ton	770.9	955.9	1248.1	2472.2	3787.2	5165.25
Efficiency of Production staff	ton/per person	8.6	13.96	28.621	47.892	69.678	83.172
Efficiency of working face	Ton/person	89.5	102.74	191.33	269.774	350.411	452.692
Efficiency of tunneling	Meter/person	0.4	0.49	0.555	0.885	1.529	1.977
Output of working face	Ton /month	166800	180570	203546	365331	408765	501115
Output of tunneling working face	Meter/month	509.31	720.28	919.11	465.34	765.82	1168.84

Table 2 The comparison of Shandong Company's efficiency among the domestic advanced mining enterprises

	2001				2002			
	Yanzhou	Datong	Kailuan	Shendong	YanZhou	Datong	Kailuan	Shandong
Staff members	113835	82778	108435		80714	107522	99552	
Yearly output(10000ton)	2800.63	3200.05	1918.46	2472.2	3609	3502.3	2233.83	3787.19
Production staff efficiency (person/ton)	14.787	4.117	4.022	47.892	14.694	4.282	3.89	69.678
Working face efficiency (ton/person)	143.013	26.099	23.975	269.774	219.097	43.410	49.981	408.765

Table 3 The comparison of Shandong Company's cost per ton among the domestic advanced mining enterprises (2003)

	Shandong	Yanzhou	Datong	Jinchneg	Luan	Kailan	Average Coal company
Material Yan/ton	4.42	17.85	20.35	15.37	11.36	16.2	21.96
Wages Yan/ton	3.21	24.54	28.22	41.95	21.67	40.84	37.6
Electricity Yan/ton	1.42	5.62	4.98	4.77	4.08	11.47	9.22
Depreciation Yan/ton	7.91	15.14	7.36	12.56	7.21	8.93	10.22
Maintenance Yan/ton	9.00	8.5	10.13	8.5	8.50	13.81	9.44
Sum Yan/ton	25．96	71.65	71.04	83.15	52.82	91．25	88.44
Accounts for totall (%)	37.4	57.4	74.9	74.9	65.6	79.6	73．6
Money Yan/ton	43.39	53.2	23.83	27.87	27.71	23.34	32.05
Accounts for totall cost %	62.6	42.6	25.1	25.1	34.4	20.4	26.6
Total cost Yan/ton	69.35	124.85	94.87	111.02	80.53	114.59	120.49

- Yan, unit of RMB, 1 Yan = 0.12US$.

Form the data in the above tables we can notice that the innovations that created the marvel of innovation at the Shandong Company. Only through whole and integrated innovations can the coal enterprises form core competition forces. Science and technology are the first production forces, but only through technological innovation can we transfer these potential production forces into actual production forces. Proven by practice, the Shandong innovations of the coal mining business is the most suitable technology model for coal enterprises so far. It is these innovations that push Shandong Company to create the first levels of productivity, economic and social efficiency, investments and costs, and reach the first class in the world mining industry.

The above described innovation system is a non-structured conception system which is why we cannot use the general way to evaluate its complexity, and therefore a new assessing method is needed. The authors have put forth the following method based on the theory of entropy theory the complexity informational content. Here the authors take the Shandong Company's innovation system as an example and use this new method to assess the innovation system complexity. This method is described in the Appendix.

Conclusion

The innovation system's structures can be optimized, improved and simplified by means of absorbing the new and advantageous models and knowledge. Here we put forth the basic form of innovation system and the essential methodology of complexity assessment. Going further, this theory and methodology can be used to assess the structural complexity for any kind of conception systems.

The innovation system is a complexity process, and there is no mature research about it at present. This is a new research field. The methodology about its complexity assessment here is a new one. It realizes the workability and practicability. Naturally the present author is indebted to many researchers and scholars both past and present in constructing what he hopes is a valuable new metric for the quantification of structural complexity. It is, of course, not sufficiently developed at this stage, and we would, accordingly, welcome constructive criticism and comments from all students and teachers in the fields of management science, as well as cognate disciplines. The author has attempted to acknowledge all those whose ideas have contributed to this present synthesis and enriched this research.

Acknowledgements

We want to acknowledge the financial support of the Natural Science Fund of China(70771060), the Production Safety and Supervision of Management Bureau of China(04-116), the National Soft Science Planed Program (2004DGQ3D090) and (2006GXQ3D154), the Natural Science Fund of Shandong Province（Y2006H10）? and the Social Science Planning Program of Shandong Province (06BJJ005) and the Soft-science Planed Program of Shandong Province (2007RKA134).

References

CAO, Qingren and SONG, Xuefeng. 2001. "The Enterprise Innovation and Management Based on Complexity Science," *Economy Management-New Management*, (14).

CAO, Qingren and SONG, Xuefeng. 2004. "The Research of Individual Behavior and Innovation Complexity of Enterprise," *Soft Science*, 3, pp. 80-82.

Gonzalez, R. 1995. "A Unified Metric of Software Complexity: Measuring Productivity, Quality, and Value. *Journal of Systems Software*, 29, pp17-37.

JIA, Renan and DING, Ronghua. 2002. *Systemic Dynamics— Feedback dynamic Complexity Analysis*. Beijing: High Education Publishing House.

Keating, E. Repenning, N. Rockart, S. 1999. "Overcoming the Improvement Paradox," *European Management Journal*, 17 (2), pp. 120-133.

Kurtyka, Jerry. 1999. "The Science of Complexity: A new Way to View Industry Change." *Journal of Retail Banking Services*, XXI (2), pp. 51-58.

LIU, Chuangeng and FU, Zhiming. 2004. *The Integration Management Research of Shandong Company*. China Industrial Economy, 1, pp107-112.

Liu, Deying. 2002. "Mine comprehensive automatic technology applied in Shenfu Dongsheng Mining Area." *Coal Science and Technology*, 30, pp. 26-29.

Song, Hualing. 1999. *The general and specific management entropy theory-the entropy theory of high entropy engineering system*. Huhehaoter：the Scientific and Technological Publishing House of Inner Mongolia.

Song, Hualing. 2000. "The entropy Evaluation of the High-entropy System and Its Determination of Operating Entropy." *Journal of System Science and Systems Engineering*, 9(3), pp. 315-323.

Song, Hualing. 2001. "Making Dynamic Production plan of enterprise under the fuzzy and random environment [J]". *Journal of System Engineering*, 16(6), pp. 411-417.

Song, Hualing. 2003. "Making Dynamic Production Plan of Coal Mining Enterprise under the Changeable Environment." *Coal Journal*, 28(1), pp. 101-107.

Song, Hualing. 2003. "Operating Disorder Complexity Assessment Of Production Systems At Coal Mining Working Face ". *Coal Journal*, 28(5), pp. 459-464.

Song, Hualing and Liu, Quanshun. 2003. "Management Entropy Theory —A New Metric Of Management System Complexity Assessment For Enterprise Organization." *Management Science Journal*, 6(3), pp19-27.

Song, Hualing. (2004). *The Management Complexity Evaluation Of Enterprise System.* Beijing: Economy And Management Publish House.

Wang, Ji-sheng and Li, Qiang. 2002. "Development And Application Of Computer Network Information System In Shenfu Dongsheng Mining Area." *Coal Science and Technology*, 2002, 30, pp. 37-39

Warfield, J.N. 1999. "Twenty Laws of Complexity: Science Applicable in Organizations." *Systems Research and Behavioral Science*, 16, pp. 3-40.

Wei, Jiang. 2004. The Evolution of Innovation System and Systemic Construction of Integration Innovation. *Natural Dialectics Communication*, (1), pp. 48-54.

Yang, JingCai. Wang, Jili. Wang, An. 2002. "Management Mode To Have High Production And High Efficiency." *Coal Science And Technology*, 30, pp. 1-7.

Yurong, Li. 2000. Discussing The Enterprise Innovation Management". *China Circulation Economy*, 5, pp. 50-53.

Zhang, Xinhua. 2002. "Analysis of the Enterprise Innovation System." *Wuhan University of Technology*, 8, pp. 105-107.

Appendix: Establishing the Entropy Models of Structural Complexity Information Content for the Innovation System

The Essence of This Research Method: According to the basic meaning of informational entropy, each basic assessing factor contributes to the average information content of the whole complexity. That is, the probability of information content, then, establishes the relations between entropy and probability.

Definition : according to the relations between probability and entropy function of Shannon's, if probability is fi=ni/n，then its information content is:

$$H = -\sum_{r=1}^{t} \frac{n_i}{n} \log \frac{n_i}{n} = -\sum_{i=1}^{t} f_i \log f_i = -\sum_{i=1}^{t} p_i \log p_i$$

The basic evaluating factor is each innovation parameter in this research problem. It is the basic unit of reduction research. Each basic assessing factor contributes to the average information content of the whole complexity. Constructing the complexity assessing basic model of innovation conception system is described as follows(tables 1 to 6):

Constructing the Model Structure of Innovation System

- The basic factors of complexity assessment

According to the research methods of complexity study from parts to the whole and from micro to macrowe evaluate the complexity by the order from notes → links→ systems. The basic factors of this study are dimensions, causalities chains (links), notes, relations, phases, layers feedback loops, etc. They reflect the complexity features. To assess and measure these basic factors contributes to the average information content of the relative whole system. Essentially, this is a measurement of the entropy information contents.

- Constructing the structural figure of complexity assessing model of innovation system

This is a problem of the multi-dimension, multi-layer, multi-phase complexity system. The sets of main systems and subsystems are:

- Innovation system complexity- performance push loop, conception innovation, technology innovation, management innovation;
- Conceptional innovation subsystem- developing conception, resource conception, management conception, technology conception, performance conception, running conception, safety conception;
- Technology innovation subsystem- technology route innovation, production technology innovation;
- Management innovation subsystem- integration management, human resource management;

The elements of the innovation subsystem sets can be divided further toget the next phases or layers.

According to the above analysis, the structural model figure of this complexity assessment has been established in figure 1.

Establishing the Entropy Models of Complexity Information Content for Each Assessing Factor

Causality chain: the arch with direction of connecting structural unit between two assessing factors. Notes: the acting points of causality, the position points of each assessing parameter as in the following figures. Crossing parameter: connecting parameters among different feedback loops. Dimension: the number of assessing parameters at each loop.

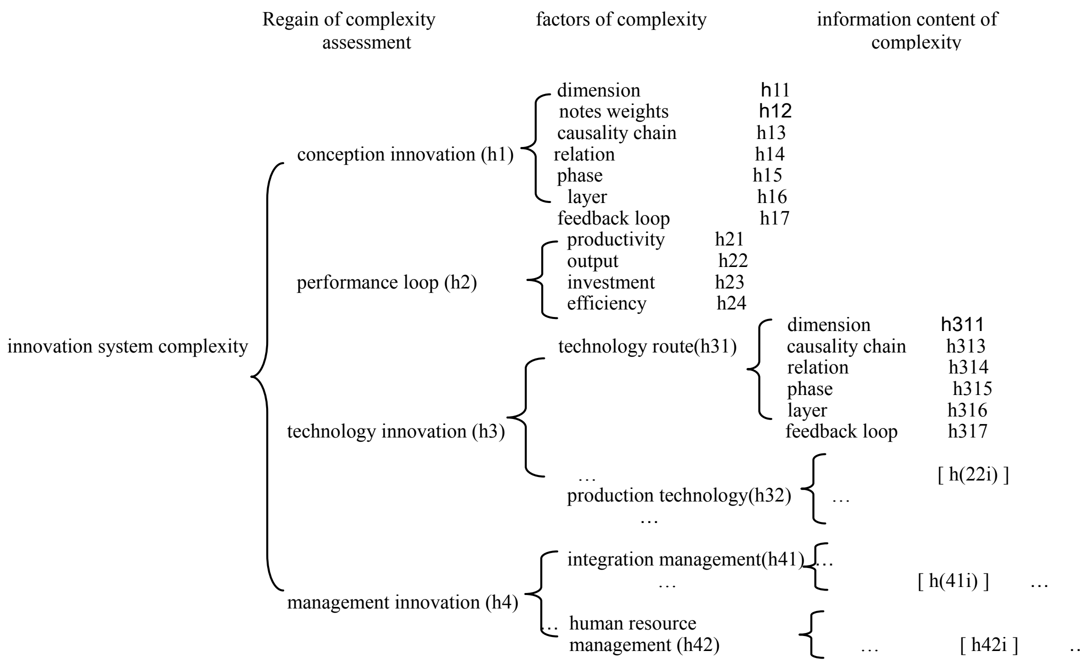

Figure 6. The structural model of innovation system complexity assessment

The measurement of complexity information for each basic parameter above is an important index of the extent of complexity. According to the basic meaning of contribution of complexity information content made by each assessing factor or parameter to the system's whole, we can model the complexity information content. The general formula is below.

The Complexity Evaluation of Innovation System

Calculating for Information Content of Each Dimension Structural Complexity Parameter

As shown in figure 6, we apply the above models to calculate the innovation system structural complexity and gain the following table 4 to 9.
Using each h volume in tables 4 to 9 and replacing the x1i and x2i volumes in formulas (15) and (16), we can gain the value of each component wi . \

Table 4. The calculation of complexity information content of innovation pushing feedback loop(w_1)

Assessing parameter	note	note weight	dimension	causality chain	relation (r) 1,	2,	3,	hc_1	hc_2	hc_3	hc_4	hcr_{11}	hcr_{12}	hcr_{13}
								hci=- ni/m log ni/m						
crossing parameter														
conception	1	4	1	1	3			0.1505	0.1479	0.1505	0.1505	0.1505		
technology	1	5	1	1	3			0.1505	0.1563	0.1505	0.1505	0.1505		
management	1	4	1	1	3			0.1505	0.1479	0.1505	0.1505	0.1505		
performance	1	4	1	1	3			0.1505	0.1479	0.1505	0.1505	0.1505		
sum	4	17	4	4	12			0.6020	0.6000	0.6020	0.6020	0.6020		

Table 5. The calculation of complexity information content of conception innovation pushing feedback loop((w_2)

Assessing parameter	note	note weight	dimension	causality chain	relation (r) 1,	2,	3,	h_{11}	h_{12}	h_{13}	h_{14}	hr_{11}	hr_{12}	hr_{13}
								hci=- ni/m log ni/m						
crossing parameter														
conception(crossing)														
development	1	2	1	1	8	1		0.1129	0.1129	0.1129	0.1129	0.1129	0.1129	
enterprise	1	2	1	1	8	1		0.1129	0.1129	0.1129	0.1129	0.1129	0.1129	
resource	1	2	1	1	8	1		0.1129	0.1129	0.1129	0.1129	0.1129	0.1129	
management	1	2	1	1	8	1		0.1129	0.1129	0.1129	0.1129	0.1129	0.1129	
technology	1	2	1	1	8	1		0.1129	0.1129	0.1129	0.1129	0.1129	0.1129	
performance	1	2	1	1	8	1		0.1129	0.1129	0.1129	0.1129	0.1129	0.1129	
running	1	2	1	1	8	1		0.1129	0.1129	0.1129	0.1129	0.1129	0.1129	
safety	1	2	1	1	8	1		0.1129	0.1129	0.1129	0.1129	0.1129	0.1129	
sum	8	16	8	8	64	8		0.9032	0.9032	0.9032	0.9032	0.9032	0.9032	

Table 6. The calculation of complexity information content of performance pushing feedback loop (w_3)

Assessing parameter	note	note weight	dimension	causality chain	relation (r) 1,	2,	3,	h_{21}	h_{22}	h_{23}	h_{24}	hr_{21}	h_{r22}	hr_{23}
								hci=- ni/m log ni/m						
performance(crossing)														
productivity	1	2	1	1	4	1		0.1397	0.1296	0.1397	0.1397	0.1505	0.1505	
output	1	2	1	1	4	1		0.1397	0.1296	0.1397	0.1397	0.1505	0.1505	
invest	1	2	1	1	4	1		0.1397	0.1296	0.1397	0.1397	0.1505	0.1505	
efficiency	1	2	1	1	4	1		0.1397	0.1296	0.1397	0.1397	0.1505	0.1505	
sum	5	12	5	5	16	4		0.5588	0.5187	0.5588	0.5588	0.6020	0.6020	

Table 7. The calculation of complexity information content of technology innovation pushing feedback loop((w_4)

Assessing parameter	note	note weight	dimension	causality chain	relation (r) 1,	2,	3	h_{311}	h_{312}	h_{313}	h_{314}	hr_{311}	hr_{312}	hr_{313}
								hijk= - ni/m log ni/m						
technology route (crossing)														
development way	1	1	1	1	4	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505
equipment selection	1	1	1	1	4	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505
tunneling technology	1	1	1	1	4	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505
auxiliary convey	1	1	1	1	4	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505
sum	4	4	4	4	16	4	4	0.6020	0.6020	0.6020	0.6020	0.6020	0.6020	0.6020
integration of technology match(crossing)														
equipment match	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1505	0.1590	0.1590
equipment system	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1505	0.1590	0.1590
equipment running	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1505	0.1590	0.1590
sum1	3	5	3	3	12	3	3	0.4770	0.4194	0.4770	0.4770	0.4515	0.4770	0.4770
structure of production technology (crossing)														
outlay of mine field	1	1	1	1	4	1	1	0.1505	0.1398	0.1505	0.1505	0.1505	0.1505	0.1505
technology of wining and tunneling	1	1	1	1	4	1	1	0.1505	0.1398	0.1505	0.1505	0.1505	0.1505	0.1505
production organization	1	1	1	1	4	1	1	0.1505	0.1398	0.1505	0.1505	0.1505	0.1505	0.1505
auxiliary convey system	1	1	1	1	4	1	1	0.1505	0.1398	0.1505	0.1505	0.1505	0.1505	0.1505
sum2	4	5	4	4	16	4	4	0.6020	0.5592	0.6020	0.6020	0.6020	0.6020	0.6020
sum								1.6810	1.5806	1.6810	1.6810	1.6555	1.6810	1.6810

Table 8. The calculation of complexity information content of management innovation pushing feedback loop((w_5)

Assessing parameter	note	note weight	dimension	causality chain	relation (r) 1	2	3	h_{411}	h_{412}	h_{413}	h_{414}	hr_{411}	hr_{412}	hr_{413}
								hijk=- ni/m log ni/m						
internal integration(crossing)														
production system	1	2	1	1	4	1		0.1590	0.1590	0.1590	0.1590	0.1590		
auxiliary system	1	2	1	1	4	1		0.1590	0.1590	0.1590	0.1590	0.1590		
multi-running	1	2	1	1	4	1		0.1590	0.1590	0.1590	0.1590	0.1590		
sum three line	3	6	3	3	12	3		0.4770	0.4770	0.4770	0.4770	0.4770		
integration of external company														
human resource	1	1	1	1	2	1	1	0.1505	0.1505	0.1505	0.1505	01505	0.1297	0.1505
technology resource	1	1	1	1	2	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1297	0.1505
sum	2	4	2	2	4	6	2	0.3010	0.3010	0.3010	0.3010	0.3010	0.3010	0.3010
sum integration management														
production organization (crossing)														
production organization	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
management organization	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
running organization	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
sum	3	5	3	3	9	3	3	0.4770	0.4194	0.4770	0.4770	0.4770	0.4770	0.4770
optimal match (crossing)														
in post	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
evaluation	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
dynamic adjustment	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
sum	3	5	3	3	9	3	3	0.4770	0.4194	0.4770	0.4770	0.4770	0.4770	0.4770
reward (crossing)														
post payment	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
technology payment	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
efficiency payment	1	1	1	1	3	1	1	0.1590	0.1398	0.1590	0.1590	0.1590	0.1590	0.1590
sum	3	5	3	3	9	3	3	0.4770	0.4194	0.4770	0.4770	0.4770	0.4770	0.4770
conception(crossing)														
human first	1	1	1	1	6	1	1	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297
cost	1	1	1	1	6	1	1	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297
resource	1	1	1	1	6	1	1	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297
dynamic	1	1	1	1	6	1	1	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297
market	1	1	1	1	6	1	1	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297
virtual conception	1	1	1	1	6	1	1	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297	0.1297
sum	6	8	6	6	36	6	6	0.7782	0.7782	0.7782	0.7782	0.7782	0.7782	0.7782
motivation (crossing)														
promotion	1	1	1	1	4	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505
upgrading	1	1	1	1	4	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505
training	1	1	1	1	4	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505
professional title	1	1	1	1	4	1	1	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505	0.1505
sum	4	6	4	4	16	4	4	0.6020	0.5592	0.6020	0.6020	0.6020	0.6020	0.6020
sum								3.5892	3.3736	3.5892	3.5892	3.5892	3.1122	3.1122

Table 9. The calculation of complexity information content of feedback loop((w_6)

Assessing parameter	stag	layer	feedback loop	relation (r) {1,	2,	3 }	hf_1	hf_2	hf_3	hfr_{11}	hfr_{12}	hfr_{13}
							hij=- ni/m log ni/m					
pushing loop	1	1	1	4								
stage (layer) 1	1	1	1	4			0.1590	0.1590	0.1129	0.1345		
performance loop	2	2	1	3	1							
conception loop	2	2	1	3	1							
technology innovation loop	2	2	1	3	1							
managing innovation loop	2	2	1	3	1							
stage (layer) 2	2	2	4	12	4		0.1590	0.1590	0.1505	0.1435	0.1388	
technology frame loop	3	3	1	1	1	4						
integrating management loop	3	3	1	2	1	4						
human resource loop	3	3	1	2	1	4						
stage (layer) 3	3	3	2	5	2	8	0.1590	0.1590	0.1505	0..1462	0.1554	0.1174
sum	3	3	8	22	7	12	0.4770	0.4770	0.4139	0.4242	0.2942	0.1174

*the structure Relation of innovation system: relations- parallel relation in same layer, direct causality relation, indirect causality relation- r_1,r_2,r_3.

The numbers of stages(layers) in this table is the location of stages(layers). Its sum is not the accumulation numbers.

$$w_1 = x_{1n}\sqrt{x_{11}^2 + x_{12}^2 + \cdots + x_{1n-1}^2} = hcr_{11}\sqrt{hc_1^2 + hc_2^2 + hc_3^2 + hc_4^2} \quad =0.7242$$

$$w_2 = x_{2n}\sqrt{x_{21}^2 + x_{22}^2 + \cdots + x_{2n-1}^2} = hr_{12}\sqrt{h_{11}^2 + h_{12}^2 + h_{13}^2 + h_{14}^2 + hr_{11}^2} \quad =1.8241.7$$

$$w_3 = x_{3n}\sqrt{x_{31}^2 + x_{32}^2 + \cdots + x_{3n-1}^2} = hr_{22}\sqrt{h_{21}^2 + h_{22}^2 + h_{23}^2 + h_{24}^2 + hr_{21}^2} = 0.7539$$

$$w_4 = x_{4n}\sqrt{x_{41}^2 + x_{42}^2 + \cdots + x_{4n-1}^2} = hr_{313}\sqrt{h_{311}^2 + h_{312}^2 + h_{313}^2 + h_{314}^2 + hr_{311}^2 + hr_{312}^2} = 2.2529$$

$$w_5 = x_{5n}\sqrt{x_{51}^2 + x_{52}^2 + \cdots + x_{5n-1}^2} = hr_{413}\sqrt{h_{411}^2 + h_{412}^2 + h_{413}^2 + h_{414}^2 + hr_{411}^2 + hr_{412}^2} = 26.5963$$

$$w_6 = x_{6n}\sqrt{x_{61}^2 + x_{62}^2 + \cdots + x_{6n-1}^2} = hfr_{13}\sqrt{hf_1^{\ 2} + hf_2^{\ 2} + hf_3^{\ 2} + hfr_{11}^2 + hfr_{12}^2} = 0.1017$$

The w_1、w_2、w_3、w_4、w_5、w_6 are the components of structural complexity of this innovation subsystem, and they can be used to assess the complexity information content of the parts. ‖w‖E is the total value of unified structural complexity information content of this system. Combining them, they can be used as a standard to assess the complexity from part to whole. The bigger their volumeis, the more complicated the system structures. We know the w_2 ,w_3's contribution to structural complexity is much bigger than w1,w_4, w_5,w_6 from analysis and verification of this case study.

The more notes, links, feedback loops and compounding relations in the systems, the more complicated the system's structure. $\|w\|_E$ is 17 in this case; it is more complicated. The decrease in complexity of systems must begin with those aspects.

Calculating the Multi-dimension and Unified Complexity Information Content

The multi-dimension and unified complexity information content can be calculated by formula (17), (18), and (19). The total values are:

$$\|w\|_{1T} = \sum_{i=1}^{n}\|\Phi_1\| = \sum_{i=1}^{5}\|\Phi(W_{k1})\| = \|B_1\| = \sqrt{hc_1^{\ 2} + hc_2^{\ 2} + hc_3^{\ 2} + hc_4^{\ 2} + hcr_{11}^{\ 2}} = 1.3452$$

$$\|w\|_{2T} = \sum_{i=1}^{n}\|\Phi_2\| = \sum_{i=1}^{6}\|\Phi(W_{k2})\| = \|B_2\| = \sqrt{h_{11}^2 + h_{12}^2 + h_{13}^2 + h_{14}^2 + hr_{11}^2 + hr_{12}^2} = 2.2123$$

$$\|w\|_{3T} = \sum_{i=1}^{n}\|\Phi_3\| = \sum_{i=1}^{6}\|\Phi(W_{k3})\| = \|B_3\| = \sqrt{h_{21}^2 + h_{22}^2 + h_{23}^2 + h_{24}^2 + hr_{21}^2} = 1.3894$$

$$\|w\|_{5T} = \sum_{i=1}^{n}\|\Phi_5\| = \sum_{i=1}^{6}\|\Phi(W_{k5})\| = \|B_5\| = \sqrt{h_{411}^2 + h_{412}^2 + h_{413}^2 + h_{414}^2 + hr_{411}^2 + hr_{412}^2 + hr_{413}^2} = 9.0709$$

$$\|w\|_{4T} = \sum_{i=1}^{n}\|\Phi_4\| = \sum_{i=1}^{7}\|\Phi(W_{k4})\| = \|B_4\| = \sqrt{h_{311}^2 + h_{312}^2 + h_{313}^2 + h_{314}^2 + hr_{311}^2 + hr_{312}^2 + hr_{313}^2} = 4.1072$$

$$\|w\|_{6T} = \sum_{i=1}^{n}\|\Phi_6\| = \sum_{i=1}^{6}\|\Phi(W_{k6})\| = \|B_6\| = \sqrt{hf_1^{\ 2} + hf_2^{\ 2} + hf_3^{\ 2} + hfr_{11}^2 + hfr_{12}^2 + hfr_{13}^2} = 0.8745$$

This is the united complexity information content of the whole system.

As

$$f_{hi} = \sum_{j=1}^{m}\frac{G_i}{m} \qquad i=1,\ldots,m. \qquad (2)$$

Then, the complexity information over all volume is:

$$H_{fh} = -\sum_{i=1}^{n} f_{hi} \log f_{hi} = -\sum_{i=1}^{n} \frac{G_i}{m} \log \frac{G_i}{m} \quad (3)$$

Then, the complexity information of the weights of assessing parameter's note i :

$$h_{iq} = n_{mi} [-\frac{1}{n_{mi}} \log(\frac{1}{n_{mi}})] = -\log \frac{1}{n_{mi}} \quad (4)$$

The complexity information content of the whole system of note weights is:

$$H_q = \sum_{i=1}^{n_m} h_{iq} = -\sum_{i=1}^{n_m} \log \frac{1}{n_{mi}} \quad (5)$$

i=1,2,…,nm, nm is the sum of notes.

Relations

Relation : the dimension of reactive relations of assessing parameters. Then, there are these relations= parallel relation in same layer, direct causality relation , indirect causality relation= r_1,r_2,r_3.

Suppose the element set of system links is $E=(e_1,e_2,...,e_n)$, $e_j(j=1,2,...,n)$ and it is the numbers of some link elements to structural system; suppose a sort of duality system between link elements $r= r_1, r_2,...,r_m$

The structural link element between systems can form a relative matrix, and its element is $r_i(e_j)$. In the order pairs $(e_j,e_{k1}),(e_j,e_{k2}),..., (e_j,e_{kt})$, the relations of each pair belong to r_i, but $e_{k1},e_{k2},...,e_{kt}$ are other elements of e. e_j.

According to Shannon's data formula[6], the entropy definition of relation r_i in element e_j is

$$h(e_j r_i) = -p[r_i(e_j)] \cdot \log[p(r_i(e_j)] \quad (6)$$

$$p[r_i(e_j)] = L_{ij} /(n-1) 。$$

Where n is the number of the whole element e set, n-1 is the most probable extension length of factor ej. It has a certain effect in structural entropy.

$$h(e_j r_i) = -L_{ij} /(n-1) \cdot \log L_{ij} /(n-1) \quad (7)$$

The total entropy of the system is:

$$H(e,r) = -\sum_{j=1}^{n}\sum_{i=1}^{3} L_{ij} /(n-1) \cdot \log L_{ij} /(n-1) \quad (8)$$

The models of phases and layers

Layers：The complexity causality relation with same features such as orders, time or circulation, etc.

A layer is an important feature of this innovation system, and it reflects the multilayer structure. The more layers it has, the more complicated it is.

If we suppose that njc is the numbers of layer j and ncis is the total number of layers, then, the complexity information contribution of layer j to the whole layers is:

$$H_{jc} = -\sum_{j=1}^{n_c} \frac{n_{ic}}{n_c} \log \frac{n_{ic}}{n_c} \qquad (9)$$

Similarly, a phase is an important feature of this innovation system too. The phase structure model of this innovation system is constructed here.

If njk is the phase's number of phases j and nt is the total number of whole system's phases, then phase j 's contribution to the phase structural complexity is:

$$H_{jy} = -\sum_{j=1}^{n_t} \frac{n_{ik}}{n_t} \log \frac{n_{ik}}{n_t} \qquad (10$$

The feedback loop

The numbers of the feedback loops reflect the simplification or complexity of the system structure.

If n_r is the feedback loop numbers of subsystem r and m is the numbers of subsystems, then n is the total number of whole systems' feedback loops and its value is:

$$n = \sum_{r=1}^{m} n_r \qquad (11)$$

fri=nr/n，then its complexity information contents:

$$H_{fz} = -\sum_{i=1}^{m} f_{ri} \log f_{ri} = -\sum_{r=1}^{m} \frac{n_r}{n} \log \frac{n_r}{n} \qquad (12)$$

Because this is the multi-dimension evaluating problem, the multi-dimension metric space model of information entropy needs to be established in order to measure the unified information content.

The abstract description of complexity information work and force

Suppose $X_n(x_i, i = 1,2,\cdots,n)$ is n-dimension vector space on the H entropy space, that is, $X_n(x_i, i = 1,2,\cdots,n) \to H^n$, $x_i \in H^n$. According to the Newton's work theorem, the following equations can be established in this complexity information force field of multi-dimension conception space.

$$w = \left\|\vec{F}\right\|\left\|\vec{D}\right\| \cdot \cos\theta$$

Here, W is 'information work' and is manifested as a vector to the particular direction. F=‖ei‖ is the force put by the distance D. θ is the angle of force. Then:

$$\vec{F} = \{x_1, x_2, \cdots, x_n\}, \left\|\vec{F}\right\| = \sqrt{x_1^2 + x_2^2 + \cdots + x_n^2} .$$

By considering the Euclidean triangular relation among vector components, we obtain：