Master dissertation

Complexity in Safety Production and Management

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Abstract

The complexity sciences, which emerged in the 1980s, are a new stage in the development of systems science and one of the frontier areas of contemporary scientific development. The development of complexity science has not only triggered changes in the natural sciences but also increasingly penetrated into the fields of philosophy, humanities and social sciences. The famous British physicist Stephen Hawking said that 'the 21st century will be the century of complexity science'.

Complexity science has made great breakthroughs and innovations in research methodology. In a sense, it can even be said that complexity science first brings about a change in methodology or thinking. Although people's understanding of complexity science is different at present, it is certain that the theory and method of complexity science will provide a new idea, new method and new way for the development of human beings, and it has a good application prospect.

Apply the scientific theory of complexity, conduct in-depth research on the composition and actual operation process of the safety production system, reveal the complexity characteristics of the system such as scale, structure, environment, dynamics, process, nonlinear action, uncertainty, etc., and obtain accident prevention management plan. It has certain theoretical and practical significance for the effective prevention and control of accidents in the safety production system.

Keywords: safety production, safety management, complexity science, complexity adaptive system, coal mine safety management

Chapter1. Safety production.

1.1. What is safety production?

Safe production refers to the elimination or control of dangerous and harmful factors in the production process to ensure personal safety and health, equipment intact and smooth production. In safe production, personal safety is to eliminate the factors that endanger personal safety and health, in the meanwhile, ensure that employees work safely, healthily and comfortably. Moreover, equipment safety is to eliminate the dangerous factors that damage equipment and products and ensure the normal operation of production.

"The most valuable asset of any production is its employees, and their safety is of utmost importance. Employee safety and security should take precedence over expediency or shortcuts in all production operations."

In short, safe production is to make the production process be carried out under the material conditions and work orders that meet the safety requirements. So it is predictable to prevent personal injuries, equipment accidents and various hazards. Consequently, to ensure the safety and health of workers and promote the improvement of labour productivity. Safety production is from the perspective of the enterprise, emphasizing that while developing production, it is necessary to ensure the safety and health of the employees and the company's property from loss.

Moreover, while ensuring the safety of personal safety equipment, you should also pay attention to that your actions should not harm others and benefit yourself.

1.2. The importance of safety production.

1.2.1. Production must be safe; safety promotes the production.

Safety production is an objective need of the modern industry. Production must be safe, safety promotes the production. This correlation scientifically reveals the dialectical relationship between production and safety, and practice proved that correlation is correct. Therefore, we must insist on the principle of safety first, and the principle of manage safety and production at the same time.

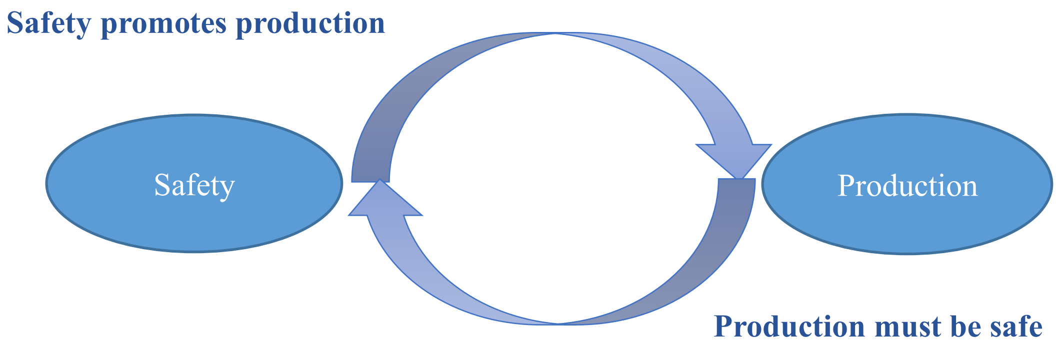

Figure1. Dialectical relationship b/w Safety and Production.

The principle of safety first means that when considering production, safety should be taken as a precondition, and various measures for safe production should be implemented to ensure the safety and health of employees and to ensure that production is continuous and safe. When there is a conflict between production and safety, safety must be first guaranteed. Safety First, for the safety management of the company, it dialectically handles the relationship between production and safety, and put people safety in the first place to protect the safety and health of employees. For employee safety, all employees of the company need to consciously observe all the rules and regulations of safety production. When doing any work, it is necessary to consider all possible risk factors and what preventive measures should be taken to avoid accidents. Consequently, to prevent personal injury and avoid unnormal production process.

The principle of manage safety and production at the same time, asking the company's management team, especially the senior management, must pay attention to safety work. Safety production should apply to all aspects of production management. Managers at all levels of the enterprise must consider the safety and production at the same time when production planning, arrangement, checking, conclusion and rating. This principle requires planning the safe production. When preparing the company's annual plan and long-term plan, production safety should be important content. Combining the company's production increase, tapping the potential, technological innovation, equipment modification, process reorganisation, and so on, to eliminate hidden dangers of accidents and improve working conditions.

1.2.2. Safety in production is everyone's responsibility.

Safety production is a comprehensive work. It is necessary to implement the principle of a combination of professional management and general management. In detail, the expert safety technicians and safety managers play their key roles in safety production, and every employee should have enough safety consciousness so that everyone pays attention to safe production and supervises each other. It is beneficial to discover hidden dangers and eliminate the risk as soon as possible. In this way, it is possible to achieve a safe production goal.

Enterprises must formulate and implement safety production responsibility systems at all levels. The safety production responsibility system is a part of the corporate job responsibility system and the most fundamental management system in the enterprise. The safety production responsibility system unifies safety and production from the organization and leadership so that when accidents occur, there is always a response plan to manage the risk and guarantee production and safety at the same time.

While formulating and implementing safety production responsibility systems at all levels, relevant safety rules and regulations should also be formulated, especially safety technical operating procedures for various types of work, so that operators have rules to follow and understand what kind of operation is safe, what kind of operation is dangerous, and the reason for safety and hazard.

In order to implement the various rules and regulations of production safety, supervision and inspection must be strengthened. Leaders at all levels of the enterprise should become an example to others, carry out the safety rules conscientiously. At the same time, they should make the supervision and inspection of safety functional departments effectively. For great examples in the safe production, it is advisable to summarize and communicate the experience and give praise and rewards. Inverse, for accidents caused by illegal command, illegal operation and violation of labour discipline, there is a need to investigate and deal with it seriously. When investigating and handling work-related accidents, the cause of the accident must be analysed, and the persons responsible for the accident should be educated and trained again by safety rules. Moreover, taking practical and feasible preventive measures.

Safety rules and regulations such as the production safety responsibility system and job safety technical operating procedures should be revised in accordance with changes in the organization of the enterprise, changes in production processes and equipment, devices, etc., and should be continuously enriched and improved by following the deepening of the understanding of the production process and the accumulation experience in the safe production, the improvement of production skills and the records of existing accidents.

1.2.3. Focus on prevention in safety production.

It is necessary to take the precaution for almost any work. So does in the safety production. Focus on the prevention, change from passive to active, and from post-event treatment to pre-prevention. Also, eliminate the accident in its budding state.

In the first place, when constructing and planning projects, safety monitoring, prevention technologies and governance measures should be designed, constructed, and used simultaneously with the main body of the project. And technologies, facilities, equipment, and devices that do not meet safety and health requirements are not allowed.

Secondly, scientific research on production safety should be actively carried out. And resolve and eliminate immediately the safety problems in operating production equipment and production process. When researching new materials, new equipment, new technologies, and new craftworks, correspondingly research and solve related safety and sanitation issues, and develop various new and reliable safety protection devices to improve the safety and reliability of production facilities.

At last, it is necessary to pay more attention to the basic work of safe production. Continuously improve the ability of employees to identify, judge, prevent and deal with accidents. For example, carry out various forms of safety education and safety technology assessment, organize safety inspections to detect and eliminate unsafe factors in time. And also, improve various detection methods, insist on the detection work, and know well about the changes in equipment and environment. Moreover, analyse the different accidents that have occurred in the past, to explore the causes and rules of accidents in the region or the company, so it is convenient to proactively take measures to prevent accidents from recurring.

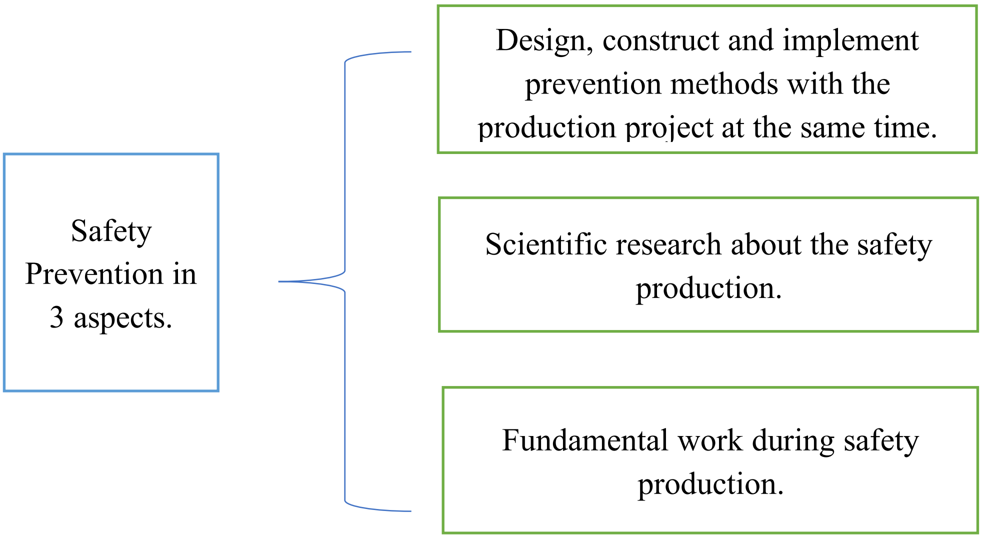

Figure2. Safety prevention during production.

1.3. The principal of safety production.

1.3.1. The principle of combining aforehand education and aforehand prevention.

Enterprise safety production is not only related to the property interests of the enterprise but also directly related to the life safety of the employees. Therefore, the safety production must be completed by the cooperation of the enterprise and the employees. The enterprise should not only perform safety inspections, strict security and other precautions, but also, it is necessary to arrange professional safety knowledge education for employees to make them aware of the importance of safe production and the necessity of preventive measures. In this way, it is possible to prevent problems before they occur.

1.3.2. The principle of aforehand prevention and rescue.

In the production and operation of an enterprise, even with strict precautions, some accidents will inevitably occur. This requires the enterprise to take emergency remedial measures after the accident, so as to reduce the losses caused to the enterprise and the damage to the employees to a minimum. After the accident is resolved, it is necessary to summarize the causes and experiences of the accident in time and apply them to aforehand prevention and education, it is consequently minimized or avoid the recurrence of the same accident.

1.4. Safe production content.

1.4.1. Safety production education.

Safety production education generally requires the education and training of enterprise employees in terms of ideology, regulations and safety technology. Consequently, employees could realize the importance of safe production and understand how to perform safe operations technically. Hence, it is beneficial to reduce or avoid the occurrence of accidents and provide protection for reducing employee casualties and corporate losses.

1.4.2. Safety inspection.

The safety inspection is also a kind of precautionary measures in enterprise safety production. The implementation of safety inspection can greatly reduce the incidence rate of accidents. Safety inspections must be executed by specialized technical personnel, and it is required to work cooperatively with employees. Such as supervision of safety inspections, reporting of hidden dangers, and so on.

1.4.3. Rescue of accidents.

The occurrence of accidents is generally sudden and unexpected. Therefore, emergency rescue plans must be prepared in advance. In the event of an accident, it is necessary to keep a cool head and implement rescue operations in order according to the predetermined plan. After the accident rescue, it is advisable to do an investigation and analysis as soon as possible, and to sum up experience and lessons. Then, strengthen the safety prevention measures to reduce the occurrence of accidents.

1.5. Influencing factors of safe production.

The main part of safe production is to control and manage safety and production at the same time. Many factors affect safe production. There are both objective factors and subjective factors. Besides, both for the reasons of the company's managers and also for the employees themselves.

1.5.1. Subjective factors.

The subjective factors that affect production safety mainly refer to human factors, which can be divided into two types according to different positions of employees in the enterprise:

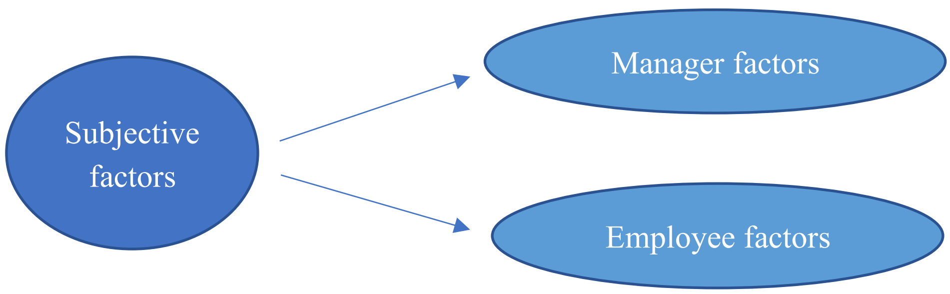

Figure3. Subjective factors that affect safety production.

1.5.1.1. The manager's factor.

The factors of managers are mainly reflected in three aspects:

- First, the manager is not responsible for the job. Such as, not doing the right things that related to the job while in the working time.
- Second, there is no safety awareness education and safety technology education for employees.
- Third, there is no timely inspection and supervision of production safety.

1.5.1.2. The employee's factor.

Another subjective factor that affects production safety is the employee's factor, which is mainly reflected in the following aspects:

- First, the safety awareness is not strong. For example, not paying attention to reading and understanding safety warning signs and safety rules, and not using labour protection products and so on.
- Secondly, failing to know well the operating methods and skills or failing to strictly follow the safety procedures.
- Third, inattention or emotional instability during working time. Some employees do not pay attention to the combination of work and rest, work overtime for a long time, and are excessively tired. As a result, they are prone to lack concentration or unstable emotion during the production process, which leads to production accidents.
- Fourth, work responsibility and discipline are not strong. This is mainly manifested in non-obedience to labour discipline, small talk at work. Moreover, insufficient coordination between each other.

1.5.2. Objective factors.

The objective factors that affect production safety can generally be divided into two categories:

1.5.2.1. The objective factors in the production process.

a	The lacking or defective of production equipment, the protection of instruments, insurance, and signal devices.
b	The defect of the equipment, instruments, tools and accessories or raw materials, etc.
c	The production process does not have sufficient safety guarantees, and the process regulations are defective.
d	The production organization and labour organization are unreasonable.
e	The lacking or defect of personal labour protection products.

Table1. The objective factors in the production process.

1.5.2.2. The unsafe factors in the work environment.

a	Poor access to the workplace. Materials, semi-finished products, and finished products are mixed. The workplace is overcrowded or improperly arranged. The ground is not flat. There are obstacles or the ground is too slippery.
b	The layout of the plant or workshop is unreasonable, no emergency exit provided, or the exit is insufficient.
c	Insufficient light or too strong light at the workplace. Therefore, it is easy to cause visual errors and cause movement errors.
d	There is over-standard noise in the workplace, causing employees to feel unstable emotions and unable to work perfectly. The temperature, humidity, and air cleanliness do not meet the standards.
e	Toxic and hazardous materials are stored over standard or improperly stored, and there is no first aid or insurance measures.
f	The factory building has been in disrepair for a long time, and the factory area is seriously polluted.

Table2. The unsafe factors in the work environment.

1.6. The complexity of safety production.

Safety production involves all aspects, a large amount and a wide range, and various contradictions and relationships are intertwined. As a systematic project, safety production requires several system supports. Such as laws and regulations system, information engineering system, technical support system, publicity, education and training system and emergency rescue system for major accidents, etc.

Production safety is a prism, where various social factors will be refracted and reflected, and at the same time affect and restrict production safety. These include social and economic conditions, the level of technological development, people's ideological awareness, moral standards, the degree of institutional perfection, traditional education and social psychology, history and culture, and so on.

The complexity of safety production is also manifested in a variety of contradictory relationships. The first is the contradiction inside and outside the safety production system. This contradictory relationship is mainly manifested as:

- The relationship between the national bureau's comprehensive management of production safety and the special management of the industry competent department.
- The relationship between the national production safety supervision and management and the local government's safety production supervision and management.
- The regional coal mine safety supervision agency and the local government's coal industry management department.
- The relationship between safety supervision and coal mine safety supervision.
- The relationship between the State Coal Mine Safety Supervision Bureau and the coal industry association and other organizations.

- Etc.

The second is the contradiction of the accident itself. Accidents are an assemblage of contradictions. The causes of accidents are complex, there are subjective reasons and objective reasons, practical reasons and historical reasons, direct reasons and indirect reasons. Accidents happen by chance and inevitability. Accidents are the most likely to cause chain reactions. Every major accident will cause many complex social problems. If not addressed properly, it will lead to serious social unrest and affect social stability.

The third is the multiplicity of safety production. Safety production is a social practice activity involving multiple levels.

Recognizing the complexity of safety production, it is necessary to overcome the simplistic and one-side thinking, arrange the safety production in all aspects and multiple aspects, mobilize the enthusiasm of all aspects, and supervise all the management at the same time.

Chapter 2. Safety management.

2.1. Safety Management Overview.

Safety management is an important part of enterprise production management, and it is a comprehensive system science. The object of safety management is the state management and control of all people, things, and the environment in production, hence, safety management is dynamic management.

Safety management is mainly to organise and implement enterprise safety management planning, guidance, inspection, and decision-making. At the same time, it is also the fundamental component to ensure that production is in the best safe state.

The content of construction site safety management can be roughly summarised into four aspects: safety organisation management, site and facility management, behaviour control, and safety technology management. In addition, manage and control specifically all people, things, and the environmental behaviour and state in production separately.

To effectively control the state of production factors, in the process of implementing safety management, it is necessary to handle five relationships correctly and follow six fundamental management principles.

2.2. The five relationships of safety management.

2.2.1. Safety and danger coexist.

Safety and danger are mutually opposed and interdependent in the movement of the same thing. Because there is danger, safety management is necessary to prevent danger. Safety and danger do not coexist in equal amounts and get along with each other in peace. With the movement and change of things, safety and danger are changing all the time. Safety and danger struggled with each other, when one is rising, the other is falling. The state of things will become the winner of the struggle gradually. It can be seen that there is no absolute safety or danger in the movement of things.

In order to maintain a safe state of production, there is need to implement variety of measures. The prevention is the priority one. Consequently, dangerous factors are completely controllable. Dangerous factors exist objectively in the movement of things, which are naturally knowable and controllable.

2.2.2. The unity of safety and production.

Production is the foundation of the existence and development of human society. During production, if people, things, and the environment are in a dangerous state, production will not proceed smoothly. Therefore, safety is an objective requirement of production. That means, when production is completely stopped, safety will lose its meaning. As far as the purpose of production is concerned, organizing safe production is one of the greatest responsibilities to the country, people and society.

When production has safety guaranteed, it will develop sustainable and stable. There are endless accidents in production activities, and production will become in a state of chaos or even paralysis. When there is a conflict between production and safety, endangering the employees or national property, it is advisable to stop the production activities for rectification and eliminate the dangerous factors. Consequently, the production situation will become better than before. Safety first does not means putting safety's priority above production. Safety and production are interactional behaviour.

2.2.3. The correlation between safety and quality.

In a broad sense, quality covers the quality of safety work, and the concept of safety also contains quality. Safety and quality are interactional, safety causes quality, vice versa. Safety first, or quality first, the priority of the two factors are not contradictory. Safety first is considered from the perspective of protecting production factors, while quality first is emphasized from the perspective of caring about product results. Safety serves quality, and quality needs safety assurance. The production will be out of control regardless of the shortage of quality or safety.

2.2.4. Mutual guarantee of safety and production speed.

In the production process, it is very undesirable to ignore quality and safety to pursue rapid production. Once misfortune happened, it is unable to guarantee the production speed. Moreover, the production time will be longer. Speed should be guaranteed by safety, in other words, safety is speed. We should pursue safe and speed at the same time and try our best to avoid time slow down by safety accidents.

There is a proportional relationship between safety and speed. It is extremely harmful that focus on improving production speed and ignore some safety problems. When there is a conflict between speed and safety, temporarily slowing down and ensuring safety is the right approach.

2.2.5. The equilibrium between safety and economic benefits.

The implementation of safety technical measures will definitely improve working conditions, and simulate the work enthusiasm of employees, and bring economic benefits, which are sufficient to compensate for the original investment. In this way, safety and economic benefit are completely consistent, and safety promotes the growth of the effectiveness of the economy.

In safety management, an investment must be moderate, appropriate, careful planning, and overall planning. It must not only ensure safe production but also be economical and reasonable. In addition, the feasibility must be considered before the production planning. It is not advisable to ignore safe production for the sake of saving money or to pursue high standards by over the budget.

2.3. The six principles of safety management.

2.3.1. Manage production and safety at the same time.

The production contains safety and safety plays a role in promoting and guaranteeing production. Therefore, although safety and production sometimes conflict, they show a high degree of consistency and complete unity in terms of the goals and objectives of safety and production management.

Safety management is an important part of production management. In the implementation process of safety and production, there is a close relationship between safety and production. Furthermore, there is a basis for co-management.

The related regulation for strengthening safety production of enterprise stated that leaders at all levels must be responsible for managing safety while managing production. Moreover, relevant safety professional institutions in the enterprise should all be responsible for achieving the requirements of safe production within their respective business scopes.

Managing production and managing safety at the same time is not only to clarify safety management responsibilities to leaders at all levels but also to clarify safety management responsibilities within the scope of business to all production-related organizations and personnel. This shows that all production-related institutions and personnel must participate in safety management and shoulder the responsibilities in management. It is a one-sided and wrong understanding that safety management is only a matter for the safety department.

The establishment of a system that all levels of personnel contributed to the safety management and implementation of management responsibilities represent the management of production and safety at the same time.

2.3.2. Adhere to the purpose of safety management.

The content of safety management is the management of the status of people, objects, and environmental factors in production, effectively controlling the unsafe behaviour of people and the unsafe status of objects and eliminating or avoiding accidents. To achieve the purpose of protecting the safety and health of workers.

It is a kind of blind behaviour to implement safety management without a clear purpose. Blind safety management is specious, waste labour's power and investment, and dangerous factors still exist. In a certain sense, blind safety management will lead to a state that threatens people's safety and health. Then, develop or transform in a more serious direction.

2.3.3. The policy of prevention first must be implemented.

The policy of safe production is safety first while prevention first. Safety first is from the perspective of protecting productivity, indicating the relationship between safety and production within the scope of production, and affirming the position and importance of safety in production activities.

Carrying out safety management is not to deal with accidents, but to apply for production activities. According to the characteristics of production, management measures are taken for production factors to effectively control the development and expansion of unsafe factors and eliminate possible accidents in the bud to ensure human safety and health in production activities.

To implement the policy of prevention first. It is necessary to know well all the unsafe factors during the production process and have a positive attitude of eliminating them. Then, choose the right time to eliminate all unsafe factors as soon as possible. When planning layout and arranging the production content, aim at the dangerous factors that may appear in the construction and production. Taking measures to eliminate is the best choice. In the process of production activities, frequent inspections, and timely discovery of unsafe factors, take measures, clarify responsibilities, and eliminate them as soon as possible.

2.3.4. Adhere to dynamic management.

Safety management is not a matter of a few people related to the production and safety agencies, but a common matter of all people involved in production. Without the participation of all staff, safety management will not be lively, and there will be no good management effect. Of course, this does not negate the role of the first person in charge of safety management and safety agencies. The role of production organizers in safety management is important, and the participation of all employees in management is also very important.

Safety management involves all aspects of production activities, the entire production process from start to finish delivery, the entire production time, and all changing production factors. Therefore, in the production activities, we must adhere to the dynamic safety management of all staff, the whole process, all-round and all-weather. One-sided, imprecise, and formalistic safety management is not advocated.

2.3.5. Safety management focuses on control.

The purpose of safety management is to prevent and eliminate accidents, prevent or eliminate accident injuries, and protect the safety and health of workers. Among the four main contents of safety management, although they are all aimed at achieving the purpose of safety management, the control of the state of production factors is more directly related to the purpose of safety management and is more prominent. Therefore, the control of the unsafe behaviour of people and the unsafe state of things in production must be regarded as the focus of dynamic safety management.

Accidents occur due to the intersection of the trajectory of unsafe behaviour of people and the trajectory of unsafe state of things. The principle of accident occurrence also shows that the control of the state of production factors should be regarded as the focus of safety management, and restraint should not be regarded as the focus of safety management, because there is no mandatory means of restraint.

2.3.6. Develop and improve in management.

Since safety management is management in changing production activities, it is dynamic. Its management means that it is constantly developing and changing to adapt to changing production activities and eliminate new risk factors. However, it is more needed is to continuously explore new laws, summarize management and control methods and experience, and guide new management after changes, so that safety management can continue to rise to new levels.

The five relationships of safety management.	Safety and danger coexist.
	The unity of safety and production.
	The correlation between safety and quality.
	Mutual guarantee of safety and production speed.
	The equilibrium between safety and economic benefits.

Table3. The five relationships of safety management.

The six principles of safety management.	Manage production and safety at the same time.
	Adhere to the purpose of safety management.
	The policy of prevention first must be implemented.
	Adhere to dynamic management.
	Safety management focuses on control.
	Develop and improve in management.

Table4. The six principles of safety management.

Chapter 3. Complexity science theory.

3.1. Introduction of complexity science.

Systems science can be divided into classical systems science and complex systems science. Classical systems science is mainly composed of classical system theory, information theory, and cybernetics. The research is mainly on linear systems, which are quite mature at present. A complete set of theories and methods have been formed at all levels from basic science, technical science to engineering application. In addition, great success has been achieved in various engineering systems.

However, many actual systems are nonlinear and complex. Some of the controlled objects are very complex, such as life, ecology, society, economy, military systems, etc. Some of the controlled objects are not very complex, but the environment of the controlled objects are very complex and the control of the objects has very special high requirements, such as robot control, weapon control system and so on. Such kinds of complex systems may exhibit a high degree of nonlinearity, polymorphic stability, time irreversibility, bifurcation, mutation, chaos, self-organization, self-adaptation, high uncertainty, and real-time characteristics. It is difficult to analyse and explain complex systems by using the theories and methods of classical systems science, and the resulting science is called complexity systems science, or simply complexity science.

The development of nonlinear science in the 1980s greatly promoted the study of complexity science. A system cannot be expressed as the sum of its parts, does not satisfy the superposition principle, and is mathematically nonlinear, which is consistent with the most important concept in complex systems theory—whole emergence.

The foundation of traditional modern science is the thought of reductionism. Reductionism believes that everything has a basic level of the smallest components. As long as the object is reduced to that level and studied clearly, all high-level problems will be solved. However, scientific development has shown that the clear study of components does not mean that the whole system is clear. The emergence of a system cannot be explained by components and must be studied from the system as a whole. This is the holism of complex systems science.

In April 1999, when the American journal - Science published the 'Complex Systems' album, the two editors titled their introduction as 'Beyond Reductionism'. Since holism is the basis of future science, which is different from modern scientific reductionism, complexity science is known as the science of the 21st century.

There are three main levels of complexity research:

1. The methodological level: most of the researchers are philosophy and social science researchers.
2. Research from the perspective of mathematical theory: such as nonlinear dynamics theory, chaos theory, random theory, etc. Most of the researchers are mathematics and physics researchers.
3. Carry out research in combination with a specific complex system: It first started from the study of the complex phenomena of inanimate systems in nature. Such systems are called complex natural systems, and then the living systems became the main research objects. For instance, biological systems and ecosystems, moreover, it has been extended to engineering systems and thinking social systems.

The main theories of early complexity science include chaos theory, dissipative structure theory and self-organization theory. Nowadays, the most researched theories are as follows:

1. Chaos control theory and its application in engineering.
2. CAS, Complex Adaptive Systems theory.
3. SOC, Self-Organized Criticality theory.
4. HOT, Highly Optimized Tolerance theory.
5. HAHC, High Assurance High consequence system and Surety science theory.

This paper will mainly introduce the concept of CAS and discuss the relationship between complex adaptive systems, and safety management. Analysis of the application of CAS in the safety management system.

3.2. Complex Adaptive Systems.

3.2.1. Overview of complex adaptive systems theory.

The theory of complex adaptive systems considers that the power of system evolution essentially comes from the inside of the system. And the interaction of micro-subjects generates macro-complexity phenomena. The research ideas focus on the interaction of inner factors of systems; therefore, its research depth is not limited to the description of objective things but focuses more on revealing the reasons for the formation of objective things and the course of their evolution.

Corresponding to the unique thinking of complex adaptive systems, its research methods are also different from traditional methods. It is a combination of qualitative judgment and quantitative calculation, microanalysis and macro synthesis, reductionism, and holism, moreover, scientific reasoning and philosophical speculation.

The core of the complex adaptive system modelling method is by using loop feedback and correlation between the local detail model and the global model, to study how the local detail changes represent the overall global behaviour. The model composition is generally an adaptive agent based on a large number of parameters. Its main approach and ideas are positive feedback and adaptation. It believes that the environment is evolutionary, and the agent should actively learn from the environment. Because of the above characteristics, the complex adaptive system theory has new and more distinctive functions that other theories do not have. Consequently, CAS provides great potential for simulating complex systems such as ecology, society, economy, management, and military.

3.2.2. History and origin of CAS.

The complex adaptive system (CAS) was formally proposed by Professor John Holland at the tenth anniversary of the founding of the Santa Fe Institute (SFI) in the United States. In 1994, John Holland gave a famous speech at the Ulam Memorial Lecture at the Santa Fe Institute - The Hidden Order. Then he published a book called 'Hidden Order: How Adaptation Builds Complexity' which proposed the theory of complex adaptive systems. The theory of complex adaptive systems is considered to be the new science of the 21st century and belongs to the third generation of systems thinking. The proposed systems concept not only completely replaces the traditional research paradigm but also is different from the earlier systems thinking.

CAS provides a new way of thinking for people to recognize, understand, control and manage complex systems. CAS theory includes both micro and macro aspects:

- At the micro-level, the basic concept of CAS theory is the adaptive, active individual, for short, the agent. This agent follows a general stimulus-response model in its interaction with the environment. Therefore, adaptability is manifested in that it can modify its own behavioural rules according to the effect of the behaviour, to better survive in the objective environment.
- At the macro-level, the system composed of such agents will develop in the interaction between the agents and between the agents and the environment, showing various complex evolutionary processes such as differentiation and emergence in the macroscopic system. Although the CAS theory was proposed not long ago, it has been applied in many fields due to its novel and enlightening ideas. In addition, it has promoted people to research more deeply on the behavioural laws of complex systems.

As the background of the CAS theory, it is necessary to make a brief introduction to the Santa Fe Institute in the United States. The Santa Fe Institute was established in 1984. With the support of many famous scientists, the first seminar was held in Santa Fe, the capital of New Mexico, in 1984. The topic of this seminar was economics, and the participants were not only many economists led by Nobel Laureate in Economics Kenneth Arrow, but also many physicists, including Nobel Laureate in Physics Murray Gell-Mann and Philip W. Anderson.

This successful exchange conference made the participants very excited and agreed to continue this kind of seminar. This is how the Santa Fe Institute was born. It is an independent, non-profit institute that supports interdisciplinary research work by applying for various funds. It was named one of the ten best research institutes in the Unites Station. The Santa Fe Institute publishes many publications, and in addition to the dozens of monographs it has published, it also publishes the journal - Complexity. To speed up the communication, the Santa Fe Institute also compiles and distributes working papers for internal communication. There are about 100 papers every year, which are not only printed and distributed but also placed on the website. This measure has greatly accelerated communications in this field. The theory of complex adaptive systems (CAS) was conceived and born in such an environment.

3.2.3. The core concept of CAS.

The basic idea of complex adaptive systems (CAS) theory can be summarized as follows:
The members of the system are called 'Adaptive Agent', or agent for short. The so-called adaptive means that it can interact with the environment and other agents. In the process of this continuous interaction, the agent continuously 'learning' or 'accumulates experience' and changes its structure and behaviour according to the learned experience.

The development or evolution of the entire macro system, including the generation of new levels, the emergence of differentiation and diversity, the appearance of new, aggregated, and larger agents, etc., are all gradually derived from this basic concept.

The complex adaptive system (CAS) theory regards the members of the system as active agents with their purpose and initiative. More importantly, CAS theory argues that this kind of initiative and its repeated and interactive interactions with the environment are the fundamental drivers of system development and evolution. Both macroscopic changes and individual differentiation can be affected by the behavioural laws of individuals. Professor Holland summed up this active, iterative interaction between the individual and the environment with the word "adaptation". This is the basic concept of CAS theory - adaptation builds complexity.

3.2.4. The key features of CAS.

People live and see many complex systems all the time, such as ant colonies, ecology, embryos, neural networks, human immune systems, computer networks and global economic systems. In all these systems, numerous independent elements interact in many aspects. In each case, these endless interactions give rise to the spontaneous self-organization of each complex system as a whole. Professor Holland called such complex systems - complex adaptive systems.

In Holland's theory, a complex adaptive system is seen as a system composed of interacting adaptive agents described by rules. These agents are constantly learning or accumulating experience, then according to the learned experience, they constantly change their rules, change their structure and behaviour, thus reflecting the ability of the agent to adapt to changes in the environment. The development or evolution of the entire macro system, including the emergence of new levels, differentiation, and diversity, and the emergence of new, aggregated, and larger agents, are gradually derived from this basis. A major part of the environment in which any particular adaptive agent lives is composed of other adaptive agents, and agents in complex adaptive systems follow a general stimulus-response model in their interactions with the environment. Therefore, the adaptation effort of any agent is to adapt to other adaptive agents. This feature is the main reason for complex dynamic models generated by complex adaptive systems.

Although there are many complex adaptive systems in different fields, and each complex adaptive system exhibits its unique characteristics, it can be found that they all have four main characteristics.

1. Based on adaptive agents.

Adaptive agents have the ability to perceive and effect. They are purposeful, initiative and positive, which means they can interact randomly with the environment and other agents, automatically adjust their state to adapt to the environment, cooperate or compete with other agents for maximum survival possibility and continuation of self-benefit. But it is not omnipotent or infallible, and wrong expectations and judgments will lead to its end. Therefore, it is the adaptability of the agent that creates the complex system complexity.

2. Co-evolution.

The adaptive agent strengthens its existence from the positive feedback it receives, and also brings opportunities for its continuation to change itself. It can change from one form of diversity unity to another. The specific process is the evolution of the agent. But adaptive agents do not just evolve, but co-evolve. Co-evolution has produced countless adaptive agents that can perfectly adapt to each other and to their living environment, just as flowers rely on the help of bees to fertilize and reproduce, and bees rely on nectar to sustain life. Co-evolution is a powerful force for mutation and self-organization of any complex adaptive system, and co-evolution always leads to the edge of chaos.

3. Tend to the edge of chaos.

The complex adaptive system has the ability to integrate order and chaos into a special balance. Its balance point is the edge of chaos, that is, various elements in a system are never static in a certain state, but they are not turbulent to the point of disassembly.

On the one hand, in order to benefit its own existence and continuity, each adaptive agent will slightly strengthen the mutual cooperation with its opponents, so that it can adjust itself well according to the actions of other agents, consequently, the whole system can co-evolve to the edge of chaos. On the other hand, the edge of chaos is far more than a simple boundary between a completely ordered system and a completely disordered system, but a self-development into a special boundary. In this special boundary, the system will produce emergence phenomena.

4. Emergence phenomena.

The most essential feature of emergent phenomena is from small to large, from simple to complex. Waldrop argues 'Complex behaviours do not from complex basic structures, but extremely interesting complex behaviours emerge from extremely simple groups of elements. Organisms co-evolved in both cooperation and competition, resulting in the formation of coordinated delicate ecosystems. Atoms search for the smallest form of energy by forming chemical bonds with each other, thus forming the well-known emergent structure of molecules. Human beings meet their material needs by buying, selling and trading with each other, thus creating the market that a popular emergent structure.'

The cause of emergent phenomena is the interaction of adaptive agents governed by one or more unrelated simple rules. The interaction between agents is the manifestation of the agent's adaptation rules. This interaction has a coupling correlation, and is more filled with nonlinear effects, making the emergent overall behaviour more complex than the sum of the parts' behaviours.

In the process of emergent generation, although the law itself will not change, the things determined by the law will change, so there will be a large number of continuously generated structures and patterns. These eternal and novel structures and patterns are not only dynamic but also hierarchical, and emergence can generate generative structures with more organizational levels on the basis of the existing structures generated. In other words, a relatively simple emergence can generate a higher-level emergence, emergence is a dynamic phenomenon that complex adapts to the overall macro-level structure of the system hierarchy.

3.2.5. Basic Properties of Complex Adaptive System Models.

Professor Holland proposed seven basic characteristics that should be possessed in complex adaptive system models around the core concept of Adaptive Agent, respectively are aggregation, nonlinearity, flow, diversity, sign, internal model and building blocks. The first four properties are general properties of complex adaptive systems that will play a role in adaptation and evolution. The last three are the mechanisms and related concepts for individuals to communicate with the environment.

1. Aggregation.

The aggregation has two meanings. The first meaning refers to a standard method of simplifying complex systems, that is, to aggregate similar agents into classes and interact with each other, which refers to the conditions for the aggregation of agents. In

this sense, aggregation is one of the main means of building complex adaptive system models. The second meaning of aggregation refers to the aggregation interaction of simpler agents, it is inevitable to emerge
complex large-scale behaviours. This outcome results from the aggregation of agents, and this emergent outcome is an essential feature of complex adaptive systems.

Agents can form higher-level agents - 'meta-agents' through aggregation. These 'meta-agents' can then be re-aggregated to produce 'meta-meta-agents'. After this process is repeated several times, the hierarchical organization of the complex adaptive system is obtained.

In the evolution of complex systems, it is a very important and critical step that smaller, lower-level individuals combine in a specific way to form larger, higher-level individuals. This is often the turning point where the macro pattern changes. However, for this step, the previous thinking method based on reductionism is difficult to explain and understand. Aggregation is not a simple combination, nor is it an annexation that eliminates individuals, but the generation of new types of individuals at a higher level. The original individuals did not disappear but developed in a new and more suitable environment for their survival.

2. Nonlinear.

Nonlinearity refers to the change of agents and their properties that do not follow a simple linear relationship. This is particularly evident in the repeated interactions of the agent with the system or environment. One of the important reasons why modern science has encountered difficulties in many aspects is that it limits its vision to a narrow range of linear relations so that it cannot describe and understand the rich and varied changes and developments.

The theory of complex adaptive systems believes that the interaction between individuals is not a simple, passive, one-way causal relationship, but an active adaptive relationship. History leaves traces, and experience affects future behaviour. In this case, the linear, simple, straight-line causal chain no longer exists, and the actual situation is often a complex intertwined relationship influenced by various feedback effects (including negative feedback and positive feedback). That's why the behaviour of the complex system is unpredictable. Moreover, it is also the reason that the complex systems undergo a tortuous evolutionary process, showing a variety of properties and states.

The theory of complex adaptive systems considers the generation of non-linearity as internal causes and the individual's initiative and adaptability. This further understands nonlinearity as an inevitable and intrinsic element of system behaviour, thus greatly enriching and deepening the understanding of nonlinearity. Because of this, when professor Holland proposed the concept of Adaptive Agent, the nonlinear characteristics of the agent's behaviour were particularly emphasized and indicated that nonlinearity is the inner reason of complexity generation.

3. Flow.

It can be seen as the flow of a certain resource on a network with many nodes and connectors. In general, nodes refer to agents, while connectors indicate possible interactions.

In complex adaptive systems, flows on the network vary over time, with nodes and connections appearing or disappearing as agents adapted and unadapted. Thus, both flows and networks change over time, and they are patterns that reflect adaptability over time and experience aggregative.

4. Diversity.

The diversity of complex adaptive systems is a dynamic pattern, and its diversity is the result of a continuous adaptation of complex adaptive systems. Each new adaptation represents possibilities for further interactions and new ecological niches. If combined with the concept of aggregation mentioned above, this is the emergence of the structure seen by the system from the macroscopic scale. In other words, the emergence of the so-called self-organization phenomenon.

5. Sign.

In the process of aggregation formation, there is always a mechanism that plays its role - Sign. In complex adaptive systems theory, the sign is a ubiquitous mechanism for aggregation and boundary generation.

The sign can facilitate selective interactions, and for mutual recognition and selection, the sign of the agent is very important in the interaction between the agent and the environment. Well-set, sign-based interactions provide a rational basis for screening, specialization, and collaboration, which allows agents and organizational structures to emerge.

The sign is the mechanism behind the hierarchical organizational structure that is common in complex adaptive systems.

6. Internal model.

Professor Holland uses internal models to define the mechanism by which the implementing agent achieves a certain function. In complex adaptive systems, when adaptive agents receive a large influx of inputs, they will select corresponding modes to respond to these inputs, and these modes will eventually become a structure with a certain function - internal models.

7. Building blocks.

Complex systems are often formed on the basis of some relatively simple components by changing the way they are combined. Therefore, the actual complexity does not depend on the number and size of the blocks but is related to the recombination of the original building blocks. The role of internal models and building blocks is to enhance the concept of hierarchy.

The diversity of the objective world is not only manifested in the diversity of individual types at the same level, but also in the differences and diversity between levels. Therefore, new laws and characteristics will appear when crossing levels. Briefly, consider the contents and rules of the low level as an internal model, then, make it as a whole to interact with other internal models at a higher level. So, it can be seen as the interaction and mutual influence between different building blocks.

Through the characterization of the above-mentioned seven basic characteristics, the complex adaptive system model can be regarded as a dynamic system that takes the internal model as the building block, aggregates through signs and interacts with each other and emerges layer by layer.

3.3. The View of Complex Adaptive System in Enterprise Safety Management.

3.3.1. Introduction.

With the development of the economy and the advancement of science and technology, the whole society has greatly strengthened and transformed the concept and understanding of safe production.

However, in general, the safety management situation of enterprises is still grim, serious accidents have caused serious social harm, and safety problems in high-risk industries are prominent. At present, most enterprises still adopt the safety management model of experience management as the mainstay and scientific management as the supplement.

Since the establishment of modern enterprise systems and the development of safety science and technology, it is necessary to develop scientific, reasonable and effective modern safety management methods and technologies for the modern enterprise. Safety management based only on experience can no longer meet the development requirements of enterprise modernization. Managers need to use more advanced management and technical methods to improve the safety management level of enterprises. A systematic safety management method is an inevitable trend for enterprises to improve their own safety management level.

Enterprise safety management covers a wide range of content and needs to organize members of different attributes to jointly accomplish security goals. How to organize and manage these complex contents is the most important problem to be solved by safety management. More importantly, how to continuously improve the enterprise safety system to adapt to the development of the enterprise. This can look at enterprise safety management issues from a different perspective.

The complex adaptability of an enterprise safety system can explain the continuous improvement of the system as it adapts to the environment. Therefore, the application of complex adaptive system theory can be a useful attempt.

The most basic concept of a complex adaptive system is that an adaptive agent is a system member. The so-called adaptive means that it can interact with the environment and other agents. In the process of continuous interaction, the agent continuously learns or accumulates experiences, and changes its structure and behaviour according to the learned experiences.

The theory of complex adaptive systems believes that adaptability creates complexity, and the members of the system are all adaptive agents with their purpose and initiative. The basic driving force of the system development and evolution is this initiative and its repeated interaction with the environment.

3.3.2. Analysis of Complex Adaptive System of Safety Management System.

In the safety management system, different organizational members can be regarded as Agents, the interaction between them is very complex, and it is difficult to describe with an effective mathematical method. In the open, dynamic and evolutionary construction of complex adaptive systems, the agents should be re-divided and each agent needs to have the characteristics of adaptability, hierarchy and openness in the safety management system.

The subsystems as shown in the figure have different tasks, responsibilities, benefit drivers, knowledge capabilities, resources, and information. Their respective behavioural decisions are proactive, and at the same time, they interact with other subsystems in information, energy, and matter. Moreover, the subsystems interact with each other. The function and interaction mechanism of each subsystem is the dynamic mechanism to make it a system with adaptability to changes in the internal and external environment.

- The CAS theory emphasizes the openness of the system. It is the constant flow of material, energy and information between the system and the environment that determines the adaptability and evolution of the system.

- The activity of the agent is reflected in its interaction with the environment. The theoretical basis is the simplest stimulus - the response model. In the safety management of modern systems, for the safety technology department, advanced safety engineering and technical methods are their reaction rules. Environment changes, technological progress, accidents, and feedback from operators, so that technicians can constantly correct safety measures and technologies, consequently, are more conducive to reducing the occurrence of accidents.

  For the safety decision-making unit of an enterprise, the macro-measures of safety management are constantly revised under the influence of the environment. The adaptability of each agent makes the whole system development to a higher level.

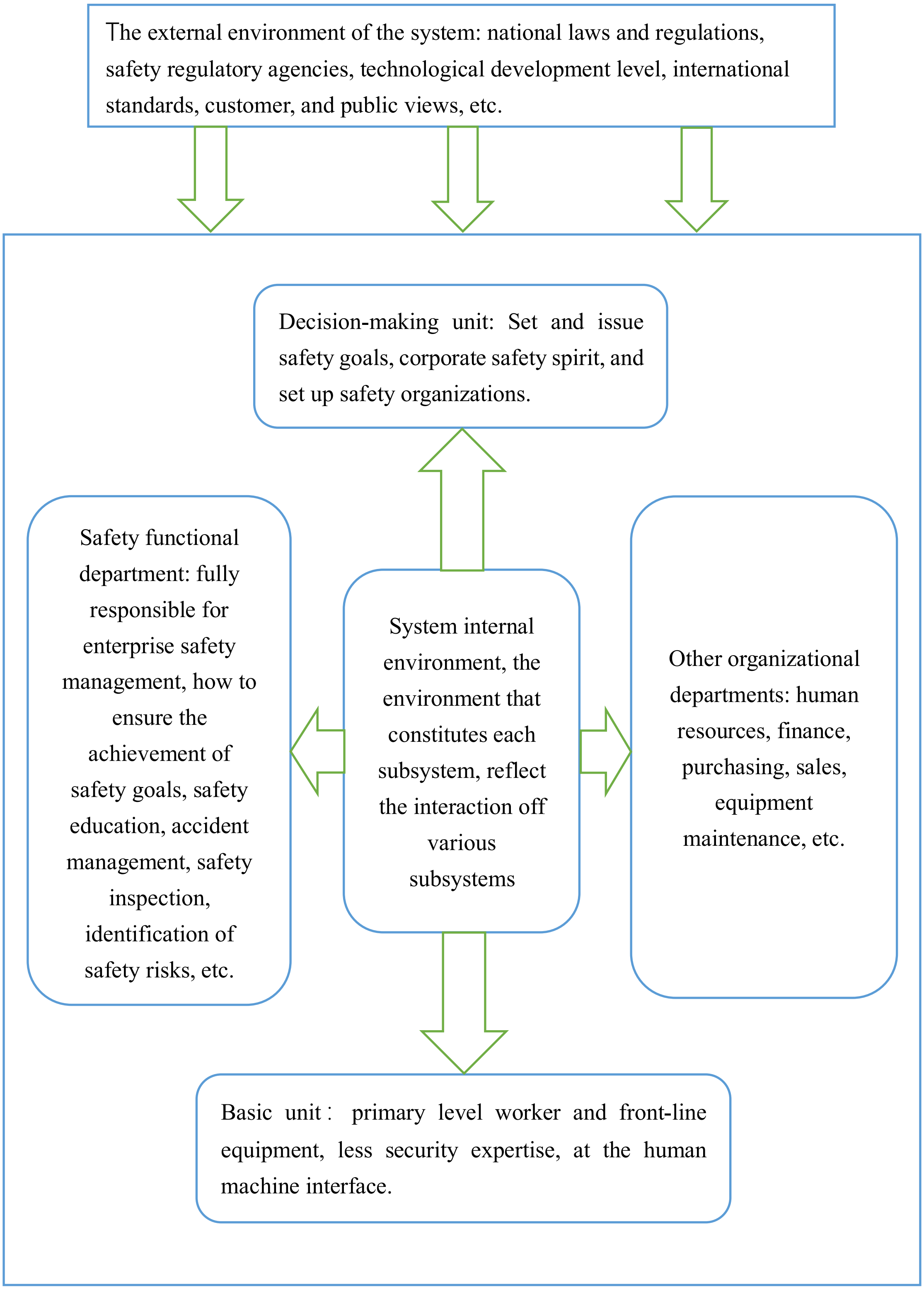

Figure4. Organizational Structure Model of Safety Management System

3.3.3. Conclusion.

This chapter discusses the application of CAS in the field of safety management, points out the complex and adaptive characteristics of a safety management system and establishes a conceptual model of a safety management system based on CAS.

This chapter establishes a three-layer conceptual model for enterprise security management, analyses the structure level of security management, briefly explains the interaction relationship between subsystems and their environment, and analyses the evolution rules of each agent. It is the theoretical preparation for further systematic research on safety management.

Chapter 4. Application of complexity science theory in coal mine safety management.

4.1. Introduction.

The coal industry is an important basic industry of the Chinese national economy. However, the coal industry is the industrial sector where accidents are frequent among Chinese enterprises, with huge casualties, severe economic losses, bad political influence, and the most critical safety production situation.

For a long time, the occurrence and development of various coal mine accidents and their evolution law have been the research focus of safety workers. When the occurrence of various accidents is determined by the complex essence of the coal mine safety production system, the essential laws of the accident are revealed by an in-depth study of the system complexity. It is very meaningful to prevent and control accidents by improving the management plan of the coal mine safety production system.

4.2. Overview of the theoretical research of complexity science.

Complexity Science is an interdisciplinary subject of Complexity Systems and Complexity. It starts with the creation of Dissipative Structure Theory (Prigogine, 1969) in the late 1960s. In just a few decades, it was born and rapidly developed a series of theories, such as Synergy (Haken, 1969), Catastrophe (Thom, 1972), Hypercycle (Eigen, 1979), Chaos, Fracture, and Self Organization, etc., and form a complex scientific theory and application system. Its theory has the properties of metascience. Although it is still under development, its research scope is not limited to specific application fields. It has applied to many fields such as physics, chemistry, nature, engineering, biology, politics, economy, culture, society, etc., and has achieved world-renowned results. It is a symbolic theory of a new stage of human understanding and development. It has become a current interdisciplinary methodology with a new way of exploring complex systems represented by nonlinear thinking. Moreover, it is hoped by people to realize the perfect combination of natural science and social science and complete the arduous mission of 'The science of 21st Century'.

The main idea of the complexity science theory is to prompt and alert people to have a systematic, complex, and holistic view when observing, analysing, and understanding things. It is necessary to explore the complexity of the system from different views and levels since things that seem random are determined by their essential characteristics.

4.3. Analysis of characteristics of the complexity of coal mine safety production system.

The coal mine safety production system is composed of many subsystems and should belong to the category of a complex giant system. The complexity of the system has the following characteristics:

1. The scale of the coal mine safety production system is complex.

The scale of the system refers to the number of system components. The formation of complexity requires a sufficient system scale, and the grand scale is a necessary condition for the formation of complexity. The coal mine safety production system is large in scale and has many links, integrating geology, surveying, mining, transportation, upgrading, ventilation, drainage, power supply, communication, lighting, support, and washing, etc., as well as employee safety training, education, supervision, and inspection and other related departments. Therefore, the huge and complex components that consist of this system determine the complexity of this system.

2. The structure of the coal mine safety production system is complex.

The fundamental reason for the complexity of the system is that the diversity and difference of the components cause the diversity and difference in the relationship between the components. Integrating components with large differences and forming a certain level of the hierarchy is the root cause of complex systems.

The coal mine safety production system mainly includes the coal mining system, tunnelling system, electromechanical system, transportation system, ventilation system, etc. Each system is composed of different subsystems. For example, the coal mining system includes coal mining machinery, working face transport machinery, supporting machinery and equipment, etc. The ventilation system includes ventilation methods, ventilation power, ventilation networks, ventilation facilities, etc. Coal-seam gas risk analysis is the basic work of ventilation system design, it needs to involve human, machine, environment, management, and other aspects. Therefore, the coal mine safety production system is extremely complex in structure.

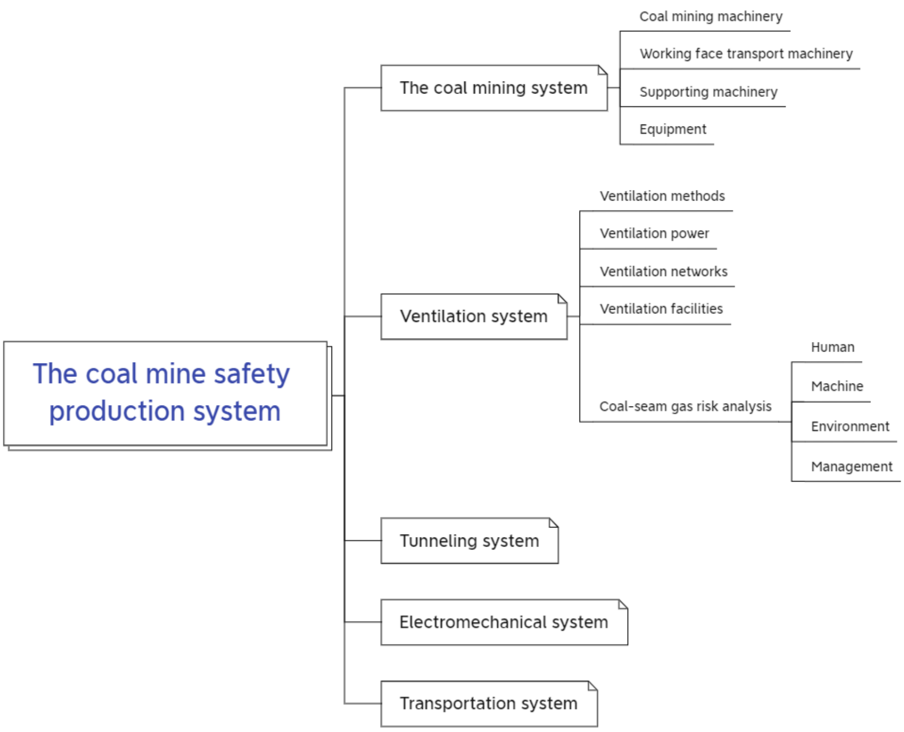

Figure5. The coal mine safety production system.

3. The environmental complexity of the coal mine safety production system.

The working environment of coal mines is mostly located in semi-enclosed spaces deep underground, where are dim and narrow, with concentrated personnel. And the environmental parameters are severely restricted by the surrounding rock, so it is difficult to carry out idealized manual adjustment. Besides, during the production process, the mixing of toxic, harmful, flammable, and explosive gases and dust makes the natural environment of coal mine safety production very harsh. Moreover, the coal mine safety production system is an open system that continuously exchanges materials and energy with the outside environment, and the influence from the outside environment to the system is not a simple interference that can be ignored.

For instance, during coal mining, the movement of roof and floor rocks, the migration of groundwater, and gas gushing are all important components in the operation of this system. In addition, the social, economic, and humanistic environment of the operation of the coal mine safety production system also has a great impact on the operation of the system.

4. The dynamic complexity of the coal mine safety production system operation.

The operation process of the coal mine safety production system is a dynamic process. The dynamic process may produce infinite diversity, difference, richness, singularity, division, chaos, sudden change and so on. The coal mining activities have destroyed the stress balance of the primary rock, and the complex dynamic phenomena that appear in the mining process have not been clearly understood until now. For this reason, there are no effective preventive measures for the mechanism of coal and gas outburst dynamic phenomena, mine earthquakes, rock bursts, and rock bursts, etc.

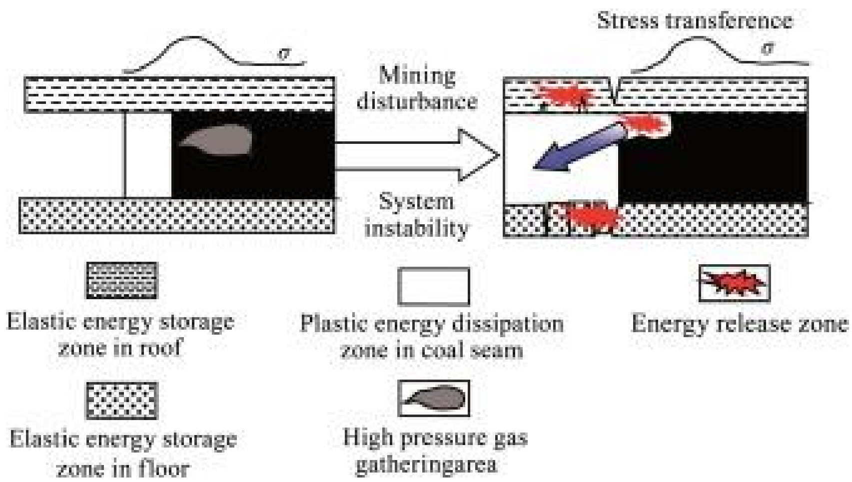

Figure 6. Effect of mining disturbance on coal and gas outburst.

5. The complexity of the irreversible process of coal mine safety production system operation.

The irreversible characteristics of the operation of the coal mine safety production system are very easy to understand. After the raw coal mining, it is impossible to return to the original state. And the gas will not be absorbed again and absorbed into the coal seam after the gas gushing. It is impossible to return to the original production state after the mining working face advanced, the mining area replaced, and the horizontal level extended. There is no turning back once the production safety accidents occur. Hence, the research on this system cannot be solved by the method of reductionism.

6. The nonlinear complexity of the coal mine safety production system.

The interaction between things is the driving force for the development and change of things. This interaction can be divided into linear and nonlinear. Linear is a single, uniform, and simple linear causality, and nonlinear is a diverse, variable, strange, and complex relationship.

Because of changes in mine pressure, movement of the roof and floor rocks, coal seam gas gushing, mine groundwater migration, rock falling, coal and gas outbursts, mine floods, and roof accidents all could happen in the coal mine safety production system. The relationship between these accidents is extremely complex and nonlinear. It is impossible to describe the relationship by several or more linear equations.

7. The uncertainty and ambiguity of the coal mine safety production system.

Certainty is simplicity and the uncertainty is complexity. The uncertainty of the coal mine safety production system is mainly manifested in the system components, the state of change, the type of safety problems, the time of occurrence, the scope of influence, and the development and change path of the accident. And the ambiguity is expressed as the precise boundaries, states, components, and their interrelationships of the system.

Consequently, due to the existence of uncertainty and ambiguity, some experts and scholars classify the coal mine safety production system as a complex grey relational system.

4.4. The thinking of accident prevention management based on the complexity of the coal mine safety production system.

4.4.1. The overall principle of coal mine safety management plan.

The coal mine safety production system is extremely complex in terms of its composition or actual operation process, but the system exists as a whole and is constantly evolving. In the past, the method of system decomposition was used, which is to decompose a complex system into several relatively simple systems. It is believed that as long as the properties of each subsystem are clearly studied, the overall nature of the system can be obtained.

The modern complexity view believes that the whole system is not a simple superposition of sub-systems, but the result of the complex nonlinear interaction between them.

To study the safety production problems of coal mines, it is necessary to grasp the operation law and development trend characteristics of the entire system as a whole, and cannot understand the problem one-sidedly from its components. Each part of the coal mine safety production system plays its roles according to the overall safety production purpose of the system. They are both interrelated and constrained by the overall goal. Of course, the whole cannot be separated from the part, and the part exists as a whole. When the relationship between part and part changes, it will inevitably affect the behaviour of the whole system.

Conversely, the behaviour of the whole system will also restrict the behaviour and structure of the parts. The whole and part are in motion change. Therefore, the research of the issues of gas, roof, mine water, etc., is only the different focus of the research object. The occurrence and development of various disasters are also interrelated.

In addition, the implementation and organizers of the coal mine safety production system are an important part of this system. Therefore, the management of the coal mine safety production system should be the overall management. It is inadvisable to ignore the mine water damage prevention and satisfied with the perfect government of the gas mine. For this reason, there is a need to formulate and implement all kinds of policies and measurements based on the overall safety goal of the mine.

4.4.2. Relevant principal of the coal mine safety management plan.

The relevance of the coal mine safety production system is not only manifested in the correlation between the internal elements of the system, the correlation between the internal elements and the external environment, but also the historical correlation of the evolution and development of the system.

The correlation between the internal elements of the coal mine safety production system means that any element of the system and other elements existing in the system are interrelated and mutually restrictive. When one of them changes, other related elements will change or adjust to maintain the best condition of the whole system. If there is a problem with the transportation system of the mine, it will directly affect the mining system, and then affect the ventilation system and the electromechanical system.

The coal mine safety production system is a highly open system, and the exchange of material, energy and information between the system and the external environment is constantly carried out. On the one hand, it is closely connected with the physical environment and interacts with each other.

For example, mine mining causes pressure changes in the mine, gas gushing, mine water, and the operation of mechanical equipment causes the temperature of the underground environment to rise, etc. On the other hand, it is also closely related to the entire society, economy, culture, and political environment.

The evolution process of the coal mine safety production system also has historical relevance. The emergence, development, and change of the coal mine safety production system is a process that evolves over time. Nowadays, the operating condition of the system is related to the current work situation but also, to a certain extent, depends on the structure and function of the past. It is generally believed that the current severe coal mine safety situation in China has a great connection with the lack of investment in the previous period.

4.4.3. The non-linear principle of the coal mine safety management plan.

The coal mine safety production system is essentially a non-linear system, and the relationship between the internal structural elements of the system and the connection with the external environment is highly non-linear.

The non-linearity of the structural relationship and internal and external relationships in the coal mine safety production system does not rule out the existence of linear relationships and the linear approximation of nonlinearity. Although many mine safety problems use linear expressions to simplify the modelling of the system, and it is better for problem explanation, but it is necessary to clearly realize that most of these linear relations are approximate and conditional.

A nonlinear system can produce chaotic behaviour. When the nonlinear system is in the condition of generating chaotic behaviour, the system has a sensitive dependence on the initial conditions. Because of this sensitivity, small factors may cause huge consequences. For instance, the failure of an electrical device may cause the catastrophic consequences of a mine gas explosion.

Non-linear effects also include different positive and negative feedback effects. Such as the increase in various safety accidents has a negative feedback effect on the overheated coal market. Under the strong pressure of the government and all sections of society, coal mine owners are encouraged to pay high attention to safety and increase investment. Under the situation with a continuously negative feedback mechanism, the coal industry will tend to develop stably and healthily. Moreover, the relationship between the output of the working face and the amount of gas emission from the working face, is a positive feedback process. As the output of the working face increases, the gas emission from the working face will increase correspondingly, leading to an increase in air volume or an increase in safety work. The positive feedback effect makes the coal mine safety production system tend to be unstable.

The coal mine safety production system is composed of multiple positive and negative feedback processes. The overall behaviour of the system is neither a simple positive feedback result nor a simple negative feedback result. The combined effect of positive and negative feedback often makes the behaviour of the system very uncertain.

4.4.4. The irreversible principle of the coal mine safety management plan.

The basic laws of physics in classical science are symmetrical to time, such as Newton's equation of motion and Schrödinger equation. After replacing -t→t, the solution of the equation remains unchanged, which means that the process has reversibility and symmetry. The non-linearity of the coal mine safety production system makes its dynamic behaviour irreversible and uncertain.

Some large mines with well-equipped safety facilities may have frequent mining accidents, some veteran workers with many years of work experience may be the initiators of certain accidents. Because the decision-making mistakes caused the destruction of the waterproof coal pillars, only other measures can be taken to prevent them. Open the water transmitting fault by mistake during the tunnelling process, which brings endless drainage, etc. These safety problems all show the uncertainty and irreversibility of the coal mine safety production system.

The uncertainty and irreversibility of the coal mine safety production system tell us that it is inadvisable to think "it may not happen" in the safety work, and any accident and its loss are irreversible.

4.4.5. The principle of dynamic imbalance in the coal mine safety management plan.

The operating status of the coal mine safety production system is unbalanced. Mine gas and mine water always change with time, and the ageing of safety facilities and equipment happens all the time, but these dynamic imbalances do not exclude the partial or instantaneous equilibrium of the system. In more detail, although it is unbalanced on the whole, it may be balanced in some parts. It seems unbalanced in the long run, but it can be balanced in a short time.

It is necessary to understand the coal mine safety production system with the idea of dynamic imbalance. The coal mine safety production system from disorder to order, from low level to high level, and must consciously and intentionally place itself in the dynamic development.

4.4.6. The principle of self-organization and evolution of the coal mine safety management plan.

A self-organizing system refers to a structured organizational system, which is self-organizing, self-creating, self-evolving, self-formation without specific instructions from the outside of the system. It is a process of structuring, systematizing, organizing, and ordering objective things themselves.

The coal mine safety production system is a kind of self-organizing system. The ultimate goal of its self-organization evolution is to realize the safe and effective operation of the system. The realization method is to make full use of its internal and internal and external nonlinear interaction. All parts of the system produce the overall behaviour together, and the overall behaviour reacts to the parts, forcing the synergy between the parts.

It can be said that non of the coal mine production safety system is established for the occurrence of mine accidents. Therefore, each system will study its own characteristics, conditions, environment, and rules in combination with its own characteristics to realize the optimization and evolution of the system.

The optimization of the coal mine safety production system has two situations: self-organization optimization and other organization optimization. Self-organization optimization is the system naturally development and optimization under certain objective environmental conditions. While the other organization optimization is an optimization process that is suffering human intervention and tending to achieve human goals.

The optimization process of the coal mine safety production system is often two optimization forms alternately or in parallel. Sometimes it will be degraded. At this time, through human intervention, the original system can be adjusted and reborn. For example, after a major accident in a mine, the system will gain vitality and make the new system play a better role after reflection and rectification.

Therefore, we should fully realize the self-organization characteristics of the coal mine safety production system, and apply the exploratory and trial-and-error evolutionary laws of human development. So that the structure and function of the evolutionary process will continue to improve. It is not recommended to manage and constraint the system based on other organizations. The essence of self-organization theory is the issue of innovation and development. The internal factors of the system are the main reason for the development of system innovation. Any external force is only an external cause and a secondary cause.

4.4.7. The internal random principle of the coal mine safety management plan.

The complexity of the coal mine safety production system is not only manifested in the complexity of its internal and internal and external relations, but also in the operation of the system will show a variety of behaviours, such as randomness, mutability, and gradual change. Therefore, a lot of people thinks that safe production in coal mines is blind luck.

Analysing the causes of many accidents, the predisposing factors are often regarded as the result of random factors inside or outside the system. For example, a worker accidentally dismantled a miner’s lamp and caused a mine gas explosion. Whatever the reason, this accidental violation is the consequence of long-term neglect of safety education, training and unsafe behaviour. When the safety production system is regarded as a complex and chaotic system, its randomness, mutability, and other characteristics can be seen as the result of its internal nonlinear mechanism and the deterministic behaviour of approximately random. Hence, there is no need to explain it by looking for random events from the outside.

4.4.8. The attractor principle of the coal mine safety management strategy.

The complexity of the coal mine safety production system is actually an uncertain change. Each accident seems to be caused by a series of system failures, but the interval between accidents shows uncertain changes. It looks like to be random and irregular. For instance, there is an accident today, then a minor injury happens on the day after tomorrow, and no accidents occur for a few consecutive months after. But through complexity research, the uncertain changing state of the coal mine safety production system can be presented as a bounded irregular body in the state space, which is a strange attractor.

The coal mine safety production system has at least two attractors at the same time, one safe attractor and the other one is unsafe. Therefore, it is difficult to predict the future state of the coal mine safety production system. Just like the Lorenz chaotic butterfly curve, with the change of system operating condition, it is difficult to accurately determine which attractor the system will enter, but the orbit always surrounds these attractors and does not repeat.

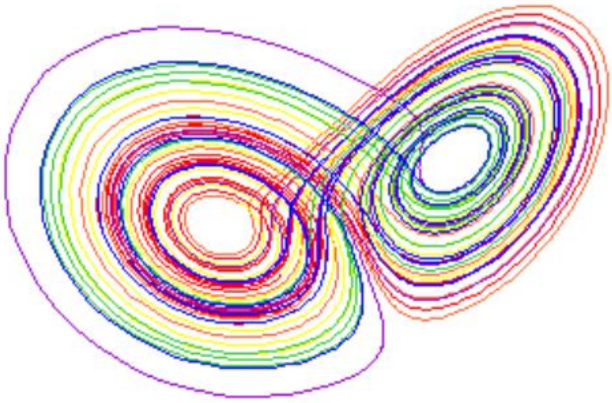

Figure7. Lorentz solution: two attractor graph.

Only by changing the position of the attractor in the state space and the type of attractor, and by carefully analysing and studying the formation of unsafe attractors, or effectively controlling the orbit of the system, can finally change the ultimate state of the system.

4.4.9. Fractal characteristics of the coal mine safety management plan.

The fractal characteristics of the coal mine safety production system are embodied in the structure, state, and change process of the system.

Structural fractal refers to the similarity between the overall structure and part of the structure in certain aspects. Such as the similarity between the bureau and mine-level safety department, personnel structure settings and the structure of the team-level safety management personnel. Moreover, the similarity between the small and big crack structure in the rock blocks.

State fractal refers to the comparability of system state behaviour on different time scales. Such as the likeness between the periodicity of long-term change and short-term change of mine gas emission.

To a certain extent, the fractal characteristics of the coal mine safety production system reflect the relationship between the whole system and its components. Thereby, providing a method to realise the behaviour of the whole system through the research of the system parts.

Conclusion.

This paper studies the basic concepts and requirements of safety production and safety management and clarifies that safety and production must be guaranteed to each other, so as to achieve maximum production benefits. Prevention is the top priority in safety production and management. Taking preventive measures in advance can avoid a lot of human and financial losses. Dynamic management is also an important part of security management.

Complexity science is the second knowledge point explored in this paper. Due to the huge and complex knowledge points, this paper mainly studies basic concepts. It mainly introduces CAS theory and some discussions in enterprise safety management.

The application of complexity science in coal mine safety production is studied. In recent years, China's coal mine safety production situation has been poor, and especially serious accidents have occurred frequently, causing heavy losses to people's lives and property, corporate economic benefits and social welfare. Although the direct cause of the accident is the unsafe behaviour of people, the unsafe state of things and the working environment, and other factors, but if talking about the root cause, it is the lack understanding of the complexity of system safety management. Therefore, it is necessary to conduct in-depth research and analysis on the complexity of system safety management, which is helpful for all levels and departments of the system to have a comprehensive understanding of the safety management system, so as to promptly and effectively cut off the formation of accident causal chains and ensure the safe operation of the system.

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