Int j simul model 13 (2014) 2, 195-209
ISSN 1726-4529 Original scientific paper

AN APPROACH TO DYNAMIC SIMULATION OF INDUSTRIAL SAFETY MANAGEMENT

Li, M.[*]; Chen, X.[**] & Zhen, P.[**]
[*] China Centre for Industrial Security Research, Beijing Jiaotong University, Beijing 100044, P. R. China
[**] School of Management Science and Engineering, Dalian University of Technology, Dalian 116024, P. R. China
E-Mail: mgli1@bjtu.edu.cn

Abstract
Achieving dynamic simulation of industrial safety management is of great significance for industrial safety management. To cover the shortage of existing simulation methods in being used in industrial safety management, especially their deficiency in integrating the theories, methods and technology achievements within multi-disciplinary and multi-field, an approach to dynamic simulation of industrial safety management is proposed in this paper based on knowledge unit and with the fusional computation of data, knowledge and model as the core of the approach. In this approach, the internal relations between data, knowledge and model are achieved by knowledge unit. And through the reasoning of knowledge unit network, the fusional computation of data, knowledge and model within various disciplines and fields is realized. Then the simulation of industrial safety management is further achieved. At the end of the paper, an example is analysed to prove the effectiveness of the proposed approach.

(Received, processed and accepted by the Chinese Representative Office.)

Key Words: Industrial Safety, Industrial Safety Management, Simulation

1. INTRODUCTION

In the 21st century, with the rapid development of economic globalization and regional economic integration, industrial safety has become the common problem that all the countries are facing. Under the assault of the global economic wave, the normal industry chain and industrial ecology of economic development were damaged in many countries, and the control of the major industries and core technologies which are concerned with the national interest and people's livelihood was also lost. The industrial safety has become the core problem which restricting the development of the national economy.

Industrial safety is an important part of national economic security. The industrial safety in China refers to all industries could develop smoothly and healthily under the fair environment of economy and trade. All the industries can obtain more space for development through their own efforts, and then the comprehensive, coordinated, steady and sustainable development of the national economic can be assured. The industrial safety management is an open complex giant system with the complex characteristics of multidisciplinary, multi-factor, complexity and multi-scale. The primary task to handle the complex industry security issues effectively is cognizing the evolution process of industrial system efficiently, which means cognizing the elements and their interaction mechanisms in the system. Thereby how the industrial safety issues happen and evolution becomes understandable. Undoubtedly, simulation is an effective approach.

At present, the approaches to dynamic simulation of industrial safety management could be classified in the following common categories: *System dynamics* (*SD*) [1], *cellular automaton* (*CA*) [2] and *Multi-Agent System* (*MAS*) [3]. All those approaches provide good idea and foundation for the dynamic simulation of industrial safety management. *SD* focuses

DOI:10.2507/IJSIMM13(2)CO6

on the overall optimal goal of the system, and deals with the complex nonlinear problems intuitively and vividly by the modelling process of "*Structure – Function*". *CA* emerges the macroscopic behaviour of the complex system by using the simple behaviour rules of cellular and the interaction rules between different cellular. *MAS* represents the macroscopic characteristics in microcosmic angle by building individual agent which is autonomous, intelligent and adaptive. Both *MAS* and *CA* could simplify the research of complex system.

But there are still some problems need to be solved. The simulation modelling process based on *SD* is relatively complicated, the functions and structure of the complex system and all kinds of complex models should be understood deeply. *CA* makes the concrete issues simple and discrete in space-time, and the cellular always are homogeneous individuals. As for *MAS*, the internal structure of agents cannot be understood clearly because of agent's structure complexity. This makes *MAS* cannot show the operation mechanism of sole agent and the influence between different agents. Additionally, the industrial safety management issues are always highly complex. It is necessary to integrate theories, methods and technologies of multi-discipline and large number of data, knowledge and model of multi-source to support the simulation process. Obviously, all the above methods don't consider the simulation of industrial safety management from this angle.

To solve the above problems, an integrated approach to dynamic simulation of industrial safety management was proposed in this paper from the perspective of system science and knowledge management. Based on knowledge unit, this approach realized the dynamic fusion calculation of data, knowledge and models through knowledge network reasoning. Then the theories, methods and technologies of multi-discipline and multi-field are comprehensively integrated. And then the simulation of industrial safety management could be further supported effectively. Because knowledge units are fine-grained and structured representation of components in the target system, to a certain extent, the complexity of *SD* method, the homogeneous unity of cellular in *CA* method and the unintelligibility of agent structure in *MAS* method could be overcome.

2. SYSTEMATICAL ANALYSIS OF DYNAMIC SIMULATION OF INDUSTRIAL SAFETY MANAGEMENT

As a special case of complex system, the industrial safety management system involves all kinds of comprehensive and ever-changing factors of nature, society, ecology, economy, culture, and so on. Dynamic simulation is the representation of objective system in the subjective cognitive space based on the total cognition of the target system. Under the circumstance of refinement of scientific research and constantly updating of knowledge, it is unnecessary to simulate industrial safety management system with theories and methods of single discipline. So integrating knowledge of various fields and disciplines comprehensively becomes the best choice to realize the dynamic simulation of industrial safety management system.

The *common feature* (at least in concept level) is the foundation of integration of multidisciplinary knowledge. Therefore, through subdividing the knowledge into basic units which need not to be divided in the industrial safety management knowledge domain, and extracting the *common* and *relevance* knowledge units, the individualized and hierarchical knowledge unit system could be constructed. *Generality* and *relevance* are also the basis of *general relationship*, so knowledge unit network can be built based on the generality and relevance and the foundation of comprehensive integration for multidisciplinary knowledge can be laid. Sufficient subdivision is the precondition of the high-efficient integration.

As mentioned above, the simulation of industrial safety management should be supported by the interaction of a large amount of multi-source and heterogeneous data, knowledge and models. Data is instance of knowledge, and knowledge is abstraction of data. *Metadata* is the bridge of data and knowledge. Therefore, the corresponding metadata and data system could be constructed through instantiating the knowledge unit system constructed above. In the process of simulation, the interaction and integration of data and knowledge is realized via metadata. Besides, due to the metadata and data system both conform to the specification of knowledge unit, the integration of multi-source and heterogeneous data can be realized based on knowledge unit.

The complicated relationships between different objective things are the basis of the interaction and evolution of the objective reality system. Generally, these relationships are depicted by models of various areas of expertise. Therefore, the dynamic simulation of industrial safety management has the demand to integrate professional models in various fields. Professional models have different forms, so the integration of related professional models to solve specific problems has been a difficult problem for researchers in management and decision making field. In this paper, common feathers of models from various fields are abstracted on the basis of knowledge unit. Accordingly, model knowledge units are established. To differentiate from common professional models, model knowledge units are called *formal models* and common professional models are called *entity models* in this paper. As the formal representation of professional models, the formal models don't have the ability of solving problems. And the entity models, which are the instantiations of the formal models, can be used to solve problems by using *operators*. Establishing associations between formal models and knowledge unit system, the entity models can be created, and then the integration of knowledge and models can be realized.

According to the above analysis, the guiding ideology of this paper is decomposing the information elements which involved in the industrial safety management into data space, metadata space, knowledge unit space, formal model space, entity model space and operator space. Through the dynamic integration of the above six spaces, the dynamic simulation of industrial safety management can be realized. The above decomposition is conducive to the collaboration of industrial safety management personnel at all levels or experts in all kinds of fields. Furthermore, in the current mobile and pervasive ICT environment, such as internet of things and Web2.0, it is also beneficial for the whole people to share, update and maintain the knowledge.

3. KNOWLEDGE UNITS AND ITS NETWORK MODEL OF INDUSTRIAL SAFETY MANAGEMENT

As for knowledge unit, there have been some certain studies from different angles. Jiang believed that knowledge unit, which can be a concept, a method, a rule, an axiom, etc., is the minimum independent units which constitute the knowledge structure and are used to represent a solution of a particular problem [4]. Dang considered knowledge unit is the controlled unit of explicit knowledge which has complete knowledge representation [5]. In respect of construction of knowledge unit, Wu proposed a KCM model which was used to construct knowledge architecture of online learning guidance system based on knowledge unit [6]. Wen gave the structure definition and interlinkage theory of knowledge unit [7].

But the above studies are all limited to knowledge representation and construction of text knowledge elements, and the primitivity and objectivity of knowledge representation should be studied in depth. Additionally, the explicit description method is commonly used in representing the relations between knowledge units, the description workload of which is enormous and may cause the incompleteness of the associated reasoning of knowledge units. To solve the above problems, this paper gives the formal representation model of knowledge unit from the perspective of objective things primitive, and puts forward knowledge unit network model based on the *implicit description* (supplemented by *explicit description*) of relations between knowledge unit attributes. Then the knowledge support for the dynamic simulation of industrial safety management can be achieved by reasoning of knowledge unit network.

3.1 Knowledge unit model

Wang put forward the concept and gave the formal representation of model knowledge unit [8]. Based on and extending its basic idea, this section proposes the knowledge unit model for industrial safety management.

(1) Object knowledge unit model

Object knowledge unit is the intellectual description of basic thing which cannot be or need not to be divided. It can be expressed as follows.

$$K_m = (N_m, A_m, R_m), \quad m \in M \tag{1}$$

$$A_m = A_m^S \cup A_m^I, \quad A_m^O \subseteq A_m^S \tag{2}$$

$$R_m \subseteq (A_m^I \times A_m^S) \cup ((A_m^S - A_m^O) \times A_m^S) \tag{3}$$

where m denotes an object, M is object set, K_m denotes the knowledge unit of m, N_m is the name set of concepts and attributes of m, A_m represents the attributes set of m, A_m^S represents the status attribute set of m, A_m^I represents the input attribute set of m, A_m^O represents the output attribute set of m, and R_m is the mapping set which is subset of $A_m \times A_m$ between attributes. R_m can describe the changes of the attribute status and interactions between attributes.

The concept set ensures the consistency of knowledge in the concept level. Concept system can be constructed based on the subject of thesaurus. All the names and concepts involved in the object knowledge unit system, the subsequent attribute specifications and attribute mapping relations should be base on the concept system to avoid the ambiguity of the subsequent knowledge reasoning.

(2) Attribute knowledge unit model

Attribute knowledge unit model is used to describe an attribute belonging to a knowledge unit. It is expressed as follows.

$$K_a = (p_a, d_a, f_a), \quad a \in A_m \tag{4}$$

where a denotes an attribute of a knowledge unit, A_m denotes the attribute set, p_a is the description of measurable characteristics of the knowledge unit. If a is measurable, d_a is the dimension. f_a is the change rule of a, and it can be a time-varying function.

(3) Relationship knowledge unit model

The relationship knowledge unit model is used to represents the mapping between the attributes belonging to a certain object knowledge unit. It is expressed as follows.

$$K_r = (p_r, A_r^I, A_r^O, f_r), \quad r \in R_m \tag{5}$$

where r denotes a relation between attributes, R_m is relation set, p_r represents attributes of r, A_r^I is the input attribute set of r, A_r^O is the output attribute set of r, f_r is a generalized function, and $A_r^O=f_r(A_r^I)$, $A_r^I \subseteq A_m^I \cup (A_m^S - A_m^O)$, $A_r^O \subseteq A_m^S$.

Based on the knowledge unit model, each knowledge unit can be divided into knowledge units of next level. The knowledge unit is named as *subclass knowledge units*, and the divided knowledge unit is named as *parent-class knowledge unit* accordingly. The subclass knowledge unit inherits the attributes of its parent-class knowledge unit, and extends its own personalized attributes. Then a hierarchical knowledge unit system which can describe the constitution and correlation mechanism of the elements in the industrial safety management system is built. This hierarchical knowledge unit system can provide basic materials for construction and reasoning of knowledge unit network and dynamic simulation of industrial safety management.

3.2 Knowledge network model

The knowledge units can form the knowledge unit network based on the domain characteristics and internal mechanism. Constructing the knowledge network model of industrial safety management can describe the evolution characteristics of the industrial safety management system in a relatively microscopic angle and provide knowledge support for the dynamic simulation of industrial safety management.

The knowledge network model is expressed as follows.

$$KN = (V, E) \tag{6}$$

$$V = \cup v_m, \quad m \in M \tag{7}$$

$$v_m = (N_m, A_m) \tag{8}$$

$$E = E_r \cup E_d \tag{9}$$

$$E_r \subseteq \cup R_m \tag{10}$$

$$E_d = \{ r_{pq} \mid r_{pq} \in (A_p^O \times A_q) \cup (A_q^O \times A_p) \}, \quad p \in M, \quad q \in M \tag{11}$$

where *KN* denotes a knowledge network, v_m is a node of *KN*, *V* is the node set of *KN, E* is the edge set of *KN*, E_r is the edge set which is made up by implicit descriptions of the relations between the attributes of nodes, and E_d is the edge set which is made up by explicit descriptions of the relations between the attributes of nodes.

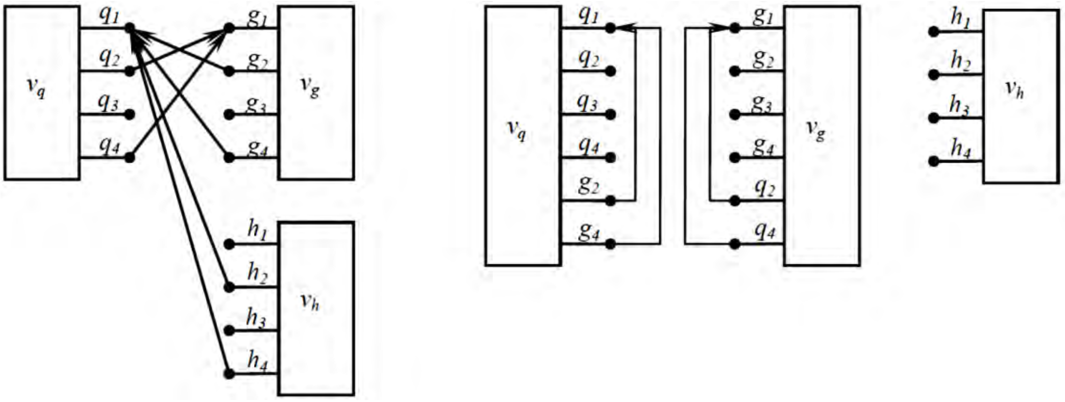
Given three arbitrary nodes v_q, v_g and v_h and their status attributes including internal state attributes and output attributes as follows:

$$A_q^S=\{q_1, q_2, q_3, q_4\}; A_g^S=\{g_1, g_2, g_3, g_4\}; A_h^S=\{h_1, h_2, h_3, h_4\}.$$

The output attributes are:

$$A_q^O=\{q_2, q_4\}; A_g^O=\{g_2, g_4\}; A_h^O=\{h_2, h_4\}.$$

Fig. 1 a) shows the possible explicit I/O relations between attributes of the three nodes. The direction of arrows means the output direction.



a) Explicit descriptions of relations

b) Implicit descriptions of relations

Figure 1: Relations between attributes of nodes.

If making the external input attributes of a node, which are output attributes of other nodes, as its own attributes, then:

$$A_q^I=\{g_2, g_4\}; A_g^I=\{q_2, q_4\}; A_h^I=\Phi .$$

And if $g_2 = h_2$, $g_4 = h_4$, then Fig. 1 a will change into the form like Fig. 1 b).

It can be seen that the basic idea of the implicit descriptions of relations between attributes of nodes is making the external input attributes of a node which are output attributes other nodes as its own attributes. By doing this, the relations between attributes belonging to different nodes can be represented as the relations between attributes of one node implicitly. On the one hand, implicit descriptions of the attributes can reduce the workload of relation description effectively and enhance the scalability of the knowledge network. On the other hand, through the intersection of attributes belonging to different nodes and with the supporting of antecedent basic concept system, the automatic identification of relation between different knowledge units, which can promote the automatic generation of knowledge unit network, can be achieved.

Due to the limitation of domain cognition, the consistence of the names of attributes belonging to different nodes which are interrelated is hard to be guaranteed. Therefore, the knowledge networks generated through implicit descriptions of the relations between different nodes are relatively complete. So the explicit descriptions of the relations between different nodes are indispensable sometimes.

4. DATA MODEL BASED ON KNOWLEDGE UNIT

Data resource management is the foundation of dynamic simulation industrial safety management. All data should conform to the knowledge structure of objective things in essence, because the data which have no association with knowledge is unaccountable and meaningless for people. Metadata not only is the bridge between knowledge unit and data, but also is the basis of fusional computation of data and knowledge. Thus, the metadata system of industrial safety management, which meets the knowledge unit attribute description specification and also can be used to describe data resource comprehensive, can be established based on the instantiating of knowledge. The relations between knowledge unit, metadata and data are shown as follows.

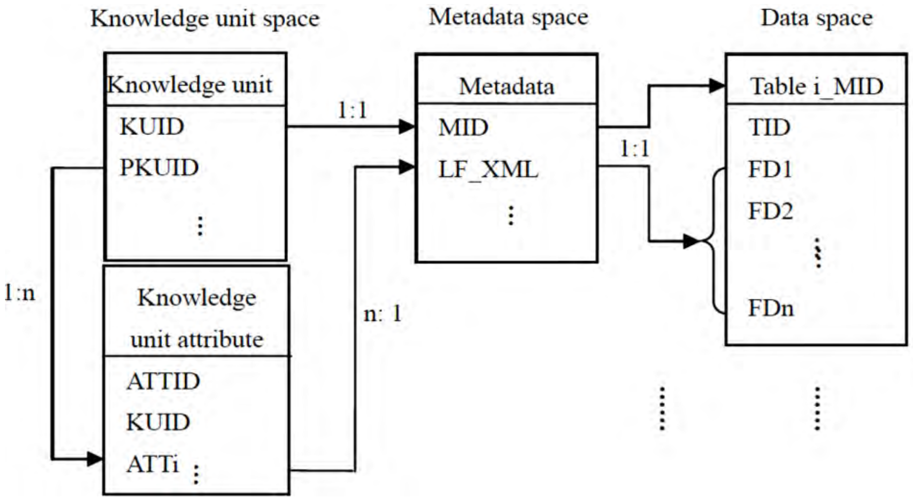


Figure 2: Relations between knowledge, metadata and data.

In Fig. 2, *KUID*, *ATTID*, *MID* and *TID* are primary keys of knowledge unit table, knowledge unit attribute table, metadata table and some specific database table respectively. *PKUID* is the identification of parent-class knowledge unit. *KUID* and *PKUID* form the tree architecture of knowledge units jointly. *ATTi* represents knowledge unit attribute, and *FDi* represents the attribute of database table, which is the instantiation of knowledge unit attribute. *LF_XML* is the metadata description of the database table "Table i_MID" which is created based on knowledge unit attribute. *LF_XML* can be stored with XML structure and in long field of database. The relation between a knowledge unit and its attributes, which is created by *KUID*, is one-to-many. The relation between the attributes of a knowledge unit and the metadata description (*LF_XML*) is many-to-one. And the metadata description has a one-to-one relation with a database table *i*.

According to the relations between knowledge unit, metadata and data, the changes of data can be reflected by metadata, and then be associated to the relevant knowledge units. On the contrary, the changes of knowledge units also can be reflected by the relevant data. Thus the interaction between data and knowledge is realized.

5. MODEL REPRESENTATION OF THE RELATIONSHIP KNOWLEDGE UNIT

According to the formula (5), the representation of relationship knowledge unit *Kr* has natural isomorphic relationship with the general model representation. Therefore, it is quite naturally to represent the relationship knowledge unit as a model, which on the one hand can lay the foundation for fusional computation of knowledge and model, and on the other hand can guarantee the integration of models belonging to multidisciplinary and multi-field models in knowledge unit network. In order to facilitate the integration of various models, this section discusses the model representation and management.

As for model representation, there have been many methods, such as subroutine representation, macro command representation, predication representation, model abstraction representation, framework representation, object-oriented representation, etc. It can be seen that the evolution trend of model representation is moving from integrated representation to some degree of decomposed representation, which makes the model representation and management become more flexible. But the existing methods are insufficient while being used in dynamic simulation of industrial safety management mainly on lack of flexibility in integrating models belonging to multidisciplinary and multi-field. Therefore, according to the dialectical philosophy, i.e. "*to integrate, decompose first*", this paper establishes formal model firstly by decomposing model into abstract elements which are relatively independent and interconnected. Then entity model is generated through instantiating the abstract and common elements of formal model based on specific knowledge units and metadata. Thus, the integrated representation and management of knowledge and model is realized (as shown in Fig. 3).

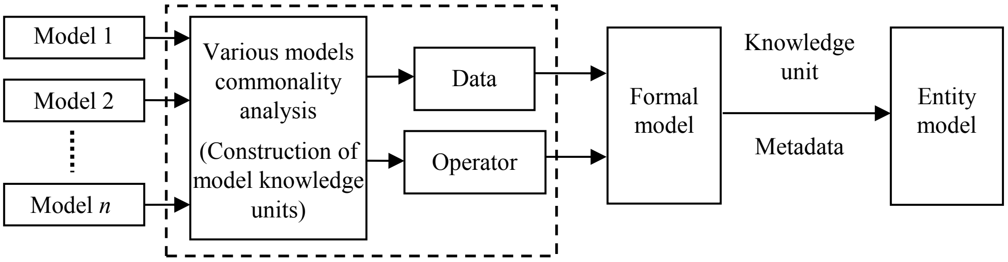


Figure 3: Model representation and management based on knowledge units.

Firstly, this method extracts the generalized common characteristics which needed in the dynamic simulation of industrial safety management based on the basic knowledge unit models to build the formal models. The formal models are highly abstract witch present one kind of similar problems, and have no relationship with specific application and computation.

Secondly, method constructs the entity models based on the specific knowledge units and the abstract and common characteristics of the formal models of metadata instantiation. The entity models can solve the specific problem which associated with specific business applications.

(1) Representation of formal model

Formal model is highly abstract and is used to represent a class of similar problems. It is application-independent and cannot be calculated or solved.

A formal model M_f can be represented as follows.

$$M_f = \left(n_f, \psi_f, \chi_f, \omega_f, \sigma_f, \zeta_f\right), \quad \forall f \in F\ , \quad F = \left\{f_r \middle| f_r \in K_r \wedge r \in R\right\} \tag{12}$$

where, n_f is the name of formal model, χ_f represents the I/O data set, ω_f is the operator used to solve the problems represented by M_f, ψ_f is the parameter set, σ_f is the parameter estimation operator, and ζ_f denotes the data set needed in parameter identification. The meanings of f_r, K_r and R are same as their meanings in knowledge unit model. When f is an adjacency matrix, ψ_f is a 0-1 matrix, and ω_f is a 0-1 and-or-not operator. Generally, σ_f and ζ_f are null in this case. When f is a logic mapping or a rule, ψ_f is a rule set of f, ω_f is the corresponding reasoning operator, σ_f is the interaction algorithm of the rule extraction, ζ_f is the description set of the involved factual data. When f is a linear equation, ψ_f is the coefficient matrix of f, ω_f is the operator of f, σ_f is the parameter estimation operator of least square method, and ζ_f is the description set of sample data of f.

χ_f, ζ_f, ψ_f, ω_f and σ_f can be described in XML form which is convenient for the computer-based management and application of the formal models. Formal model only includes the constraints and specifications of I/Os, parameters and operators, and the descriptions of specific data are not involved in the representation of formal model. This ensures the generality of formal model. The final forms of ω_f and σ_f can be executable programs or solvers realized by any programming languages.

(2) Generation of entity models

The generation of entity model is the instantiation process of all the elements of the formal model M_f. The specific process is as follows.

① Establishing mappings between the I/O data set χ_f and specific knowledge unit attributes

Through embedding the specific descriptions of knowledge unit attributes in the I/O data XML of M_f, the abstract descriptions of I/Os in M_f are instantiated, and the mappings between knowledge unit attributes and the I/O constraints and specifications are established.

Because the I/Os of M_f and its operator ω_f are corresponding to each other, once the mappings between χ_f and specific knowledge unit attributes are established, the mappings between I/Os of ω_f and specific knowledge unit attributes are also established.

② Establishing mappings between the parameter identification data set ζ_f and specific data sample

Through embedding the specific descriptions of data sample, that is metadata, in the parameter identification data set XML of M_f, the abstract descriptions of sample data set in M_f are instantiated, and the mappings between concrete sample data and the constraints and specifications of parameter identification data set are established. Thus, the parameter estimation operator σ_f can get the concrete data sample at run time to compute the parameter set ψ_f, namely the concrete values of parameter set of operator ω_f.

Formal model is in essence a model class, and entity model is an object of formal model. The significance and effect of decomposing model into formal model and entity model is providing a standardized management mode for all kinds of models, enhancing the universality of model representation and making it easy for experts to focus on business modelling and analysis, besides easy to integrate the models in each professional field and be integrated with knowledge unit model mentioned above.

6. DYNAMIC SIMULATION OF INDUSTRIAL SAFETY MANAGEMENT

As discussed above, this paper gives the formal representations of knowledge, data and model involved in the dynamic simulation of industrial safety management. This section proposed the approach to dynamic simulation of industrial safety management based on the interaction of data, knowledge and model from the perspective of comprehensive integration.

6.1 General description of the approach to dynamic simulation

It can be seen from the first section that the main idea of this paper is realizing dynamic simulation of industrial safety management through dynamic integration of data space, metadata space, knowledge unit space, formal model space, entity model space and operator space. The interaction process of the six spaces is shown in Fig. 4.

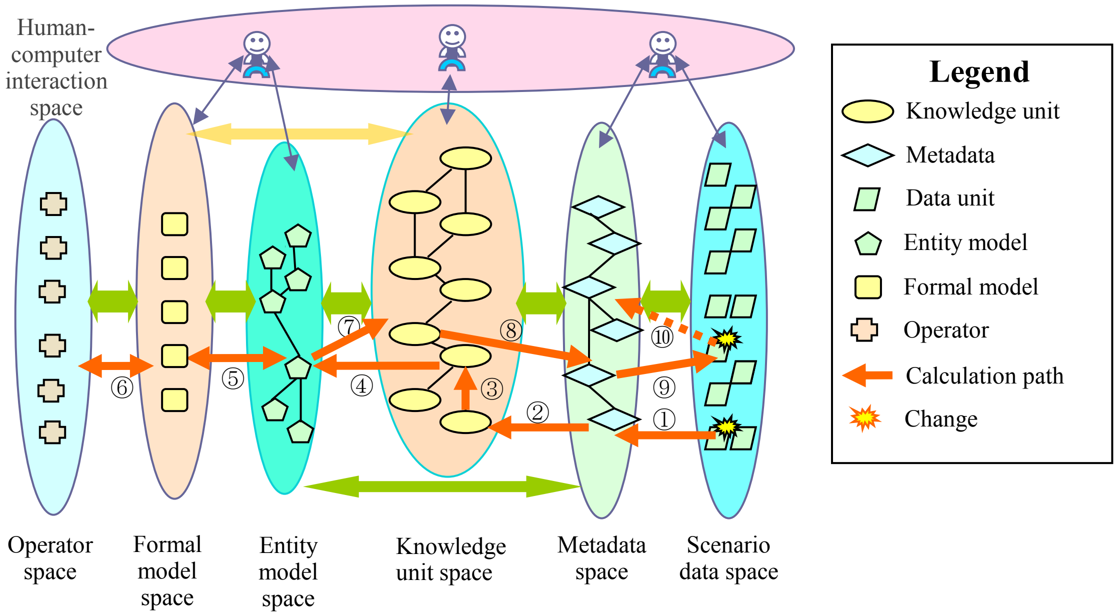


Figure 4: Dynamic simulation of industrial safety management based on fusional computation of data, knowledge and model.

In Fig. 4, the labelled arrows indicate a subprocedure of simulation. Step ① indicates that the change of a scenario data unit is monitored by data engine and passed on to the corresponding metadata. In step ②, the data change is further passed on to corresponding knowledge units via metadata. Through the reasoning of knowledge unit network, the interrelated knowledge units are activated in step ③. After analysing the relations between attributes of the active knowledge units, the need entity models are obtained in step ④. In step ⑤, the corresponding formal models are located by parent-child relationship of formal model and entity model. In step ⑥, the corresponding operators are called by formal models to calculate the result of entity models. Then the knowledge units corresponding to the calculated results in step ⑥ are achieved in step ⑦. Step ⑧ realizes the guidance of the knowledge units achieved in step ⑦ to special metadata. And then the relevant data in scenario space are refreshed through step ⑨. After the above subprocedure, step ⑩, that is another subprocedure of simulation, is triggered once again.

Here a brief introduction of the concept of scenario needs to be made. Scenario is the representation of the status of all the relevant subjective and objective entities involved in industrial safety management system. It is in continuous development. Under the scenario concept, the essence of the dynamic simulation of industrial safety management is the simulation of its scenario evolution.

6.2 Fusional computation of data, knowledge and model based on knowledge unit network reasoning

Starting from scenario data, the fusional computation of data, knowledge and model which based on knowledge unit network reasoning integrates data, knowledge and model dynamically to realize the dynamic simulation of industrial safety management. In the simulation process, the knowledge unit network is the core and models are the computing units.

Based on a specific scenario, a knowledge network is instantiated as an entity network. In the instantiation process, a knowledge unit can be instantiated as multiple entities. The essence of the fusional computation of data, knowledge and model is the change of status of one or more entity attributes will cause the change of other relevant entity attributes through the relation models between the nodes of entity network. The termination condition of fusional computation is the entity network's reaching steady state or the number of iterations' reaching the threshold. The criterion of entity network's steady state is the change intervals of attribute status values of all the relevant entities in entity network less than the preset threshold. The process of the fusional computation is shown in Fig. 5.

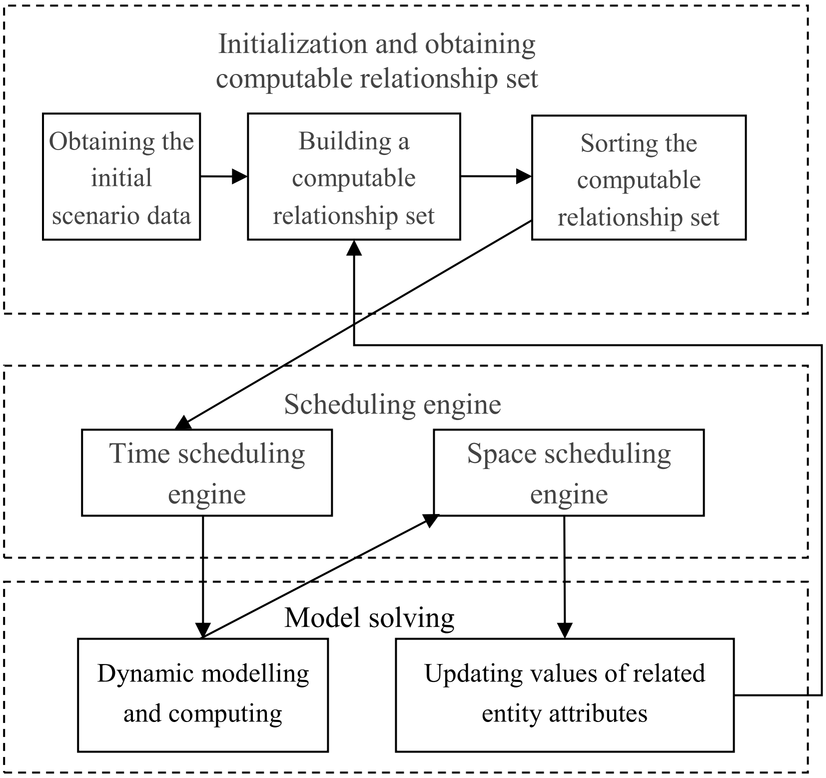


Figure 5: Fusional computation of data, knowledge and model based on knowledge unit network reasoning

Suppose the entity network instantiated by knowledge unit network *KN* is *EN*, then:

$$EN = (V', E') \tag{13}$$

$$V' = \cup v'_m, \quad m \in \{1, 2, \cdots, n\} \tag{14}$$

$$v'_m = (N_m, A_m, AV_m) \tag{15}$$

$$E' = E'_r \cup E'_d \tag{16}$$

$$E'_r \subseteq \cup R'_m \tag{17}$$

$$R'_m \subseteq (AV^I_m \times AV^S_m) \cup ((AV^S_m - AV^O_m) \times AV^S_m) \tag{18}$$

$$E'_d = \{ r_{pq} \mid r_{pq} \in (AV^O_p \times AV_q) \cup (AV^O_q \times AV_p) \}, \quad p, q \in (1, 2, \cdots, n) \tag{19}$$

where n is the number of nodes in *EN*, *V'* is the node set of *EN*, v_m*'* is and arbitrary node of *EN*, AV_m is the attribute value set of v_m*'*, $AV_m = AV^S_m \cup AV^I_m$, $AV^O_m \subseteq AV^S_m$. *E'* is the edges set of *EN*, E'_r is the recessively described edge set of *EN*, E'_d is the explicitly described edge set of *EN*.

(1) Acquisition of the computable relation set

Computable relation is the relation in entity network whose input attributes are all satisfied and whose output attributes all act on the entities in entity network within current reasoning cycle. Suppose the computable relationship set is $R_{computable}$, then

$$\mathrm{R}_{computable} = \{ r \mid r \in E' \wedge A^I_r \subseteq AV' \wedge A^O_r \subseteq \cup A_m \}, \quad m \in \{1, 2, \cdots, n\} \tag{20}$$

$$\mathrm{A}V' = \{ a_i \mid a_i \in A_m \wedge av_i \in AV_m \wedge av_i \text{ is not null} \} \tag{21}$$

where *AV'* is the attribute set in which each attribute has been assigned a specific value.

(2) Sorting the computable relation set

According to the discussion in section 4, there are two classes of the relations between knowledge unit attributes. One is the relations between the attributes belonging to the same knowledge unit, and the other is the relations between the attributes belonging to different knowledge units. Therefore, the relations between entity attributes can also be divided into two classes, which are the relations between the attributes belonging to the same entity and the relations between the attributes belonging to different entities. The relations between the attributes belonging to the same entity are used to describe the changes of the entity's own attribute status, and the relations between the attributes belonging to different entities are used to describe the interactions between different entities. Generally, the changes of the entity's own attribute status are always prior to its influence on other entities. According to this criterion, the computable relation set can be sorted, and then the ordered computable relation set which satisfying space-time constraints can be built.

(3) Space-time scheduling engine

Space-time attribute is the essential attribute of anything, and the interactions between all the things should satisfy the space-time constraints. Therefore, the reasoning of entity network should follow the space-time constraints between entity attributes, and the relation set which used to describe the edge set of entity set should be scheduled orderly by *space-time scheduling engine*. By setting the clock cycle of reasoning, the *time scheduling engine* can update the entity attribute set, whose status values need to be updated within current clock cycle, to the latest status values at the end of this clock cycle. The *space scheduling engine* is used to judge whether the influence relationships between attributes of different entities should be activated or not. The method of judgment is that the space-time scheduling engine gets the space attributes of the relationship-related entities and computes the spatial distance between the entities. Only when the distance is less than a reasonable threshold, the corresponding relationship is activated and the computing result is assigned to the related entity attributes.

(4) Dynamic modelling

The *dynamic modelling* is such a process that getting corresponding formal models via entity models which are used to describe the relationships between entity attributes, obtaining the corresponding operators via the acquired formal models, and instantiating the I/O parameters of operators based on entity attribute values. The instantiated operators can be used in model solving. The dynamic modelling process is shown in Fig. 6.

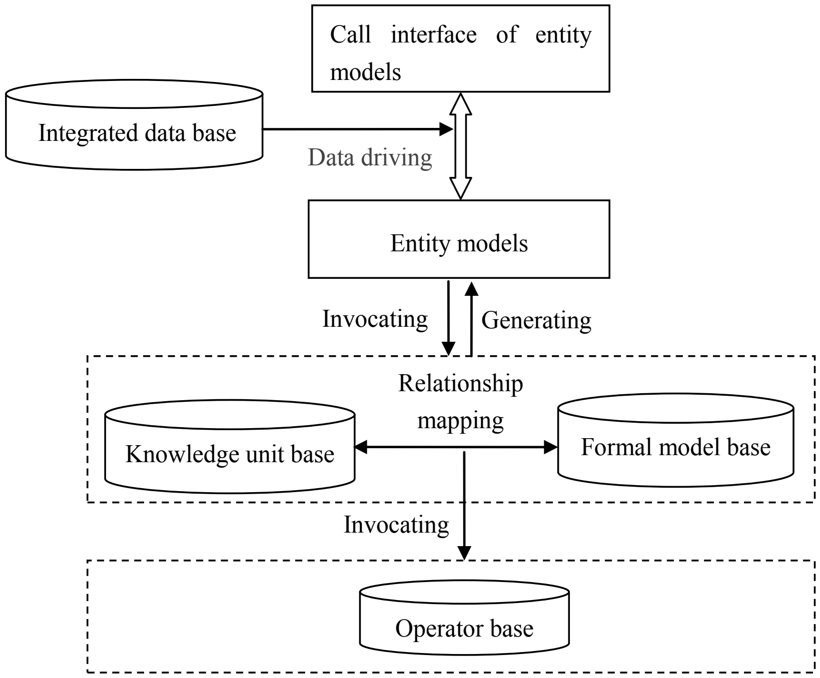


Figure 6: Dynamic modelling process.

7. A SIMULATION EXAMPLE

In this section, a simulation example of economic operation of high-tech industries is put forward to demonstrate the application process and to prove the scientificalness and effectiveness of the proposed approach.

7.1 The knowledge units of major economic indicators for economic operation of high-tech industries

According to the discussion of section 3.1, the knowledge unit of major economic indicators of economic operation of high-tech industries can be represented as below.

$$K_{indicators} = (N_{indicators}, A_{indicators}, R_{indicators})$$

$$A_{indicators} = (A^{I}_{indicators}, A^{S}_{indicators}, A^{O}_{indicators})$$

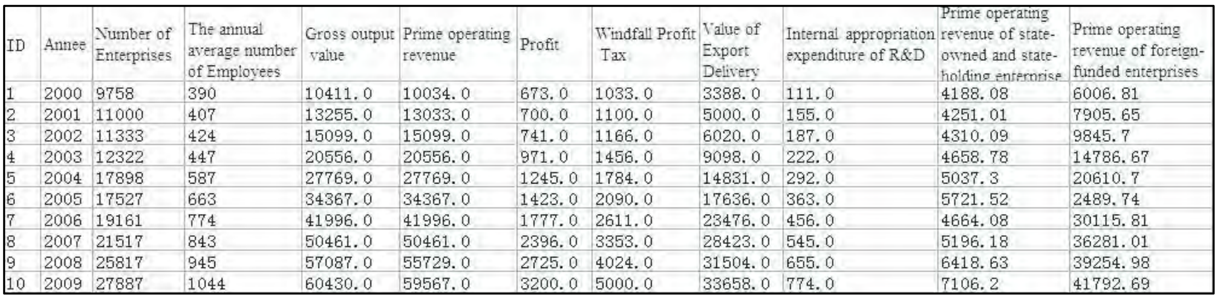
All the attributes in $A_{indicators}$ can be described from the aspects of the attribute type, the value range, the time-varying characteristics, etc. In this section, the knowledge unit of major economic indicators only has internal state attributes. The brief description of the internal state attributes set is as follows.

$A^{S}_{indicators}$={*Annee*, *Number of enterprises*, *The annual average number of Employee*, *Gross output value*, *Prime operating revenue*, *Profit*, *Windfall profit tax*, *Value of export delivery*, *Internal appropriation expenditure*, *Prime operating revenue of state holding enterprises*, *Prime operating revenue of foreign-funded enterprises*}

As to $R_{indicators}$, it includes a BP neural network model which is used to reflect the relationships between all the indicators.

7.2 The data sample

According to the knowledge units given in section 7.1, the table structure that is metadata, of major economic indicators can be generated. Based on this table structure, the data sample used to simulate the economic operation of high-tech industries can be acquired from the China Statistical Yearbook. The partial metadata and data information for the simulation of the economic operation of high-tech industries are given in Fig. 7.



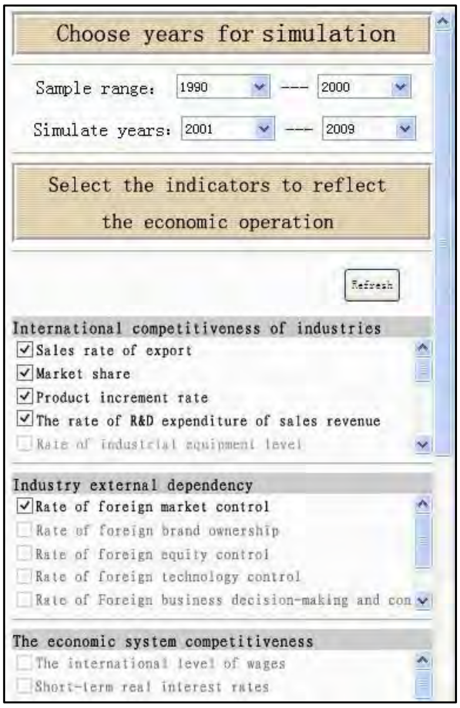
ID	Annee	Number of Enterprises	The annual average number of Employees	Gross output value	Prime operating revenue	Profit	Windfall Profit Tax	Value of Export Delivery	Internal appropriation expenditure of R&D	Prime operating revenue of state-owned and state-holding enterprise	Prime operating revenue of foreign-funded enterprises
1	2000	9758	390	10411. 0	10034. 0	673. 0	1033. 0	3388. 0	111. 0	4188. 08	6006. 81
2	2001	11000	407	13255. 0	13033. 0	700. 0	1100. 0	5000. 0	155. 0	4251. 01	7905. 65
3	2002	11333	424	15099. 0	15099. 0	741. 0	1166. 0	6020. 0	187. 0	4310. 09	9845. 7
4	2003	12322	447	20556. 0	20556. 0	971. 0	1456. 0	9098. 0	222. 0	4658. 78	14786. 67
5	2004	17898	587	27769. 0	27769. 0	1245. 0	1784. 0	14831. 0	292. 0	5037. 3	20610. 7
6	2005	17527	663	34367. 0	34367. 0	1423. 0	2090. 0	17636. 0	363. 0	5721. 52	2489. 74
7	2006	19161	774	41996. 0	41996. 0	1777. 0	2611. 0	23476. 0	456. 0	4664. 08	30115. 81
8	2007	21517	843	50461. 0	50461. 0	2396. 0	3353. 0	28423. 0	545. 0	5196. 18	36281. 01
9	2008	25817	945	57087. 0	55729. 0	2725. 0	4024. 0	31504. 0	655. 0	6418. 63	39254. 98
10	2009	27887	1044	60430. 0	59567. 0	3200. 0	5000. 0	33658. 0	774. 0	7106. 2	41792. 69

Figure 7: The metadata and data information of the major economic indicators for economic operation of high-tech industries.

7.3 Scenario customization and simulation

(1) Scenario customization

The scenario customization is setting the initial condition for the simulation. The scenario customization includes choosing the data sample interval and appropriate indicators used to reflect the economic operation status. The scenario customization of this example is shown in Fig. 8.



Choose years for simulation

Sample range: 1990 --- 2000

Simulate years: 2001 --- 2009

Select the indicators to reflect the economic operation

International competitiveness of industries
☑ Sales rate of export
☑ Market share
☑ Product increment rate
☑ The rate of R&D expenditure of sales revenue
☐ Rate of industrial equipment level

Industry external dependency
☑ Rate of foreign market control
☐ Rate of foreign brand ownership
☐ Rate of foreign equity control
☐ Rate of foreign technology control
☐ Rate of Foreign business decision-making and con

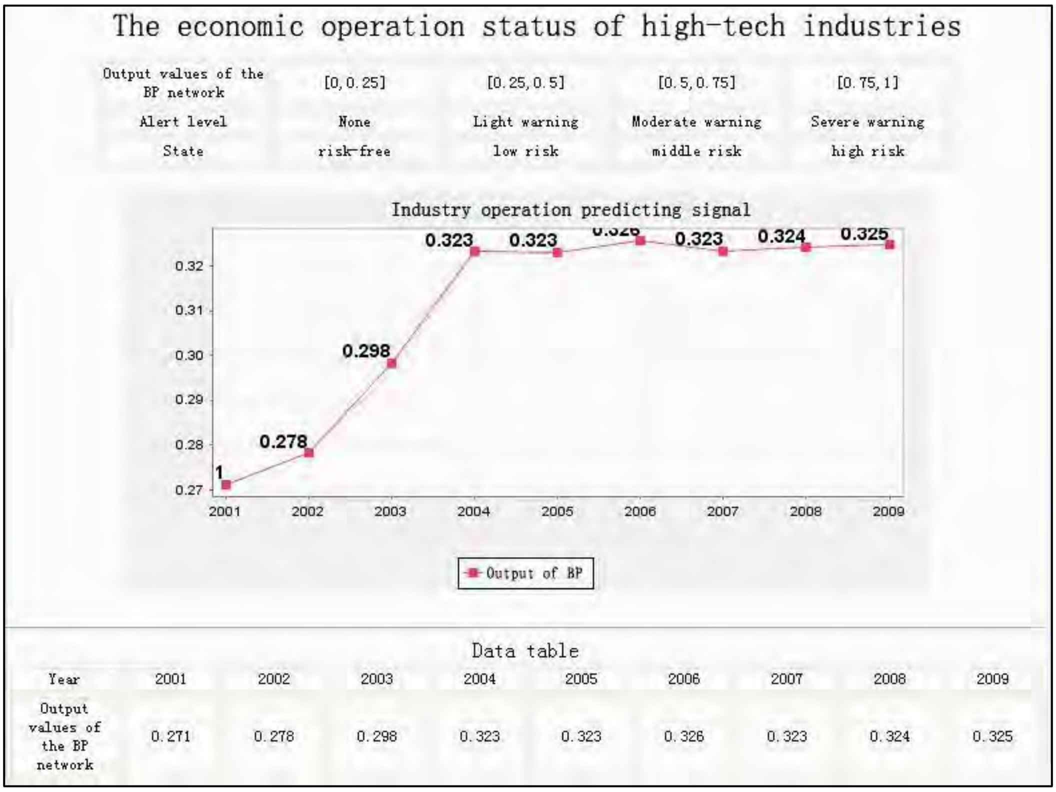
The economic system competitiveness
☐ The international level of wages
☐ Short-term real interest rates

Figure 8: Scenario customization.

It can be seen from Fig. 8 that the aim of this example is to simulate the economic operation status of high-tech industries between years 2001 to 2009 based on the sample data between years 1990 to 2000. The economic operation status is comprehensively reflected by the indicators of sales rate of export, market share, product increment rate, the rate of R&D expenditure of sales revenue and rate of foreign market control.

(2) Simulation for the economic operation status of high-tech industries

Fig. 9 shows the simulation result of the economic operation status of high-tech industries between years 2001 to 2009 based on the customized initial scenario and the BP neural network model.



The economic operation status of high-tech industries

Output values of the BP network	[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
Alert level	None	Light warning	Moderate warning	Severe warning
State	risk-free	low risk	middle risk	high risk

Data table

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Output values of the BP network	0.271	0.278	0.298	0.323	0.323	0.326	0.323	0.324	0.325

Figure 9: Simulation of the economic operation status of high-tech industries.

To clearly illustrate the economic operation status of high-tech industries, the aggregative indicator value calculated by BP neural network model based on the indicators of sales rate of export, market share, product increment rate, the rate of R&D expenditure of sales revenue and rate of foreign market control is partitioned some intervals, whose interval value are [0, 0.25], [0.25, 0.5], [0.5, 0.75] and [0.75, 1] respectively, indicating the economic operation status of risk-free, low risk, middle risk and high risk respectively.

It can be seen from Fig. 9 that the economic operation status is good and has no risk in 2001. And from years 2002 to 2009, the economic operation is in low risk status.

8. CONCLUSION AND PROSPECT

In this paper, the shortages of the several kinds of common simulation method, such as SD, CA and MAS, while being used in the dynamic simulation of industrial safety management, especially their deficiency in integrating the theories, methods and technology achievements within multi-disciplinary and multi-field, are summarized firstly. Then a comprehensive integrated approach to dynamic simulation of industrial safety management is proposed from the perspective of system science and knowledge management. This approach makes knowledge units as its base and the fusional computation of data, knowledge and model as its core. Through the reasoning of knowledge unit network, the fusional computation and comprehensive integration of data, knowledge and model within various disciplines and fields is realized. Then the simulation of industrial safety management is further achieved. Knowledge units are fine-grained and structured descriptions of the components in the domain or target system. Therefore, the complexity of the SD method, the homogeneous of the cells in CA method and the structure unintelligibility of Agents in the MAS method could be overcome. At the end of this paper, a simulation example of economic operation of high-tech industries is put forward to demonstrate the scientificalness and feasibility of the proposed approach.

As discussed in the introduction, knowledge units are the base of the proposed approach. So, it has the vital significance to build complete knowledge unit system for realizing the dynamic simulation of industrial safety management. But it has a huge amount of work to build complete knowledge unit system. To solve this problem, we are studying the automatic and semi-automatic knowledge unit acquisition method which is Wikipedia-oriented and based on semantic analysis. The details will be given in subsequent works.

9. ACKNOWLEDGEMENTS

This work was supported by the Research Foundation from Ministry of Education of China (Grant No. 239010522), the Research on China Industrial Security Index (Grant No. B09C1100020), the National Natural Science Foundation of China (Grant No. 91024029, 71203019, 71373034), the Specialized Research Fund for the Doctoral Program of Higher Education of China (Grant No. 20110041120028), the Humanities and Social Science Youth Fund Project of Ministry of Education of China (Grant No. 11YJC630023), the Social Science Planning Fund Project of Liaoning Province of China (Grant No. L13DGL061), and the Fundamental Research Funds for the Central Universities of China (Grant No. DUT14RW108).

REFERENCES

[1] Jiang, W. (2012). *Researches on circular economy system based on system dynamics for coal enterprise*, Tianjing University, Tianjing

[2] Luo. L. Z. (2011). *Research of the production process of a company based on cellular automata*, Shanghai Jiao Tong University, Shanghai

[3] Qu, Z. G.; Cui, Y. F.; Deng, Y. J. (2013). Research of development capability of green agricultural based on multi-tasking agent, *Ecological Economy*, Vol. 4, 102-105

[4] Jiang, Y. C.; Yang, H. Y.; Zhang, L. B. (2007). Research of knowledge organization and system service functions based on knowledge unit, *Theory and Explore*, Vol. 30, No. 1, 37-40

[5] Xi, Y. J.; Dang, Y. Z. (2008). Enterprise top management team characteristic's heterogeneity to strategic decision influence – An empirical study based on chinese private enterprise, *Journal of Industrial Engineering and Engineering Management*, Vol. 22, No. 3, 1-4

[6] Wu, C.-H. (2004). Building knowledge structures for online instructional/learning systems via knowledge elements interrelations, *Expert Systems with Applications*, Vol. 26, No. 3, 311-319, doi:10.1016/j.eswa.2003.09.003

[7] Wen, Y. K.; Xu, G. H. (2003). Knowledge element linking theory, *Journal of the China Society for Scientific and Technical Information*, Vol. 22, No. 6, 666-670

[8] Wang, Y. Z.; Ye, X.; Qiu, J. N. etc. (2010). Emergency management information system-fundamental principles, *Key technologies and Cases*, Science Press, Beijing, 94-102