2010 International Conference on Intelligent System Design and Engineering Application

Development and Application of Dynamic Intelligent Risk Management System throughout Shield Tunneling

TengLi1
Shanghai Institute of Applied Mathematics and Mechanics
Shanghai University
Shanghai, China
flyingtl@126.com

Hu Min2, Wu Fangfang2
Sydney Institute of Language and Commerce
Shanghai University
Shanghai, China
Minahu@163.com

Abstract—The risk management issue of shield tunneling has attracted full attention for these years, but the current methods of risk identification and risk management cannot meet the safety requirements. This paper addresses the complexity of shield tunneling construction as well as the uncertainty of the underground environment, and then a new Logical Arrangement Risk Evaluation (LARE) method and an improved clonal selection algorithm (ICSA) are used to enhance the efficiency and accuracy of risk identification. Based on the practical situation of underground projects in China, this paper adopts an iterative dynamic risk management concept and aims at the comprehensive risk management during the whole construction processes by making full use of the current communication and information technologies. Thus a dynamic intelligent system for whole processes shield tunneling project risk management has been developed and introduced to the practical applications. The results show that the system can identify the potential risks and proposes effective risk pre-control technical measures to ensure the safety of projects.

Key words: Shield tunneling, Dynamic, Intelligent, Risk management system

I. INTRODUCTION

Shield tunneling is now widely used in the urban underground projects. As the complexity and uncertainty of the underground environment, it is highly important to monitor and control the risks during the whole construction processes to avoiding the potential loss.

The British Tunneling Society and the Association of British Insurers jointly delivered the "Joint code of practice for risk assessment of tunnel works in the UK" [1] in September 2003. The International Tunneling Association Working Group released the guidelines for tunneling risk management in 2004 [2]. The International Tunneling Insurance Group (ITIG) issued the “Guidelines for tunneling risk management"[3] in January 2006, And China has also published "A code of practice for risk management of tunnel works" in 2007 [4].

Shield tunneling has quite complex processes, involving foundation reinforcement, base installment, back support, and many other steps. Meanwhile, different technics will be used in different works even in the same process. For example, the foundation reinforcement, there are brine freezing method, liquid nitrogen freezing method, mixing pile method, jet grouting pile method, dewatering method and soil-cement mixed wall to be selected. As the causes for risks and the monitoring methods of different processes and technics are quite different, The source of information, types and sampling interval are also different, which makes extremely difficult to establish the whole

978-0-7695-4212-6/10 $26.00 © 2010 IEEE
DOI 10.1109/ISDEA.2010.126

processes shield tunneling risk management system.

Shield tunneling risk management and the development of risk information system are inseparable. Chungsik Yoo(2006)[5]combined geographic information system with artificial neural network to develop the IT-based tunneling risk management system (IT-TURISK) which can assess the risks during the excavation, especially risk assessment for the surrounding environment and third-party damage and its application in the subway project in Seoul. Italian GeoDATA company (2006) [6] published the GeoData Master System (GDMS) for the risk management of geo-engineering projects, which adopted GIS and WEB technology to monitor the risk of buildings. The system has been applied to many metro projects, such as St. Petersburg, Rome and Santiago etc. Huang (2006)[7] developed the "Shield Tunneling Risk Management Software (TRM1.0) "according to the expert experiences, which is used in the Shanghai Yangtze river tunnel project. Shanghai Tunnel Engineering Co., Ltd (2004)[8]developed "The Intelligent Remote Management Information System of Shield Tunnel Construction", providing effective construction management and technical support by data analysis. Viewing the characteristics of information system, some information systems focus on risk assessment during the early construction stage; the other systems emphasize real-time risk analysis during construction stage, but which depend on the complex and expensive monitoring devices.

Underground projects risk management systems usually have three problems: 1) Methods currently used for risk assessment mainly roots in the financial (insurance) risk management, which lacks further research and not entirely suitable for tunneling risk analysis. 2) The entire tunneling has many steps. One Consider environmental monitoring data as the sign of risk to identify cannot cover the whole shield tunneling process. 3) The development of risk is a dynamic process, which requires "iterative" risk management, but the current risk assessment for sign information analysis and pre-control is not enough. Therefore, emphasizing on pre-warning and adopting pre-control measures to avoid Accident Occurrence, which is the ultimate goal of risk management.

Combing with practical engineering situation and expert experience, this paper aims at the comprehensive risk management during the whole construction processes, adopting an iterative dynamic risk management concept to identify risk information. This paper also builds a dynamic intelligent system for whole processes shield tunneling project risk management. The paper is divided into five parts. First, it proposes two new intelligent decision methods, the Logical Arrangement Risk Evaluation (LARE) method and an improved clonal selection algorithm (ICSA), to analyze the underground projects risk features. The Second part describes the design of flexible information flow based on the whole construction processes. Then, the third part illustrates the construction of the overall risk management information system. The last parts include the practical application and the conclusion.

II. New Intelligent Risk Identification Methods

A. Logical Arrangement Risk Evaluation (LARE)

Analytic Hierarchy Process (AHP) and Fault Tree Analysis (FTA) are the most common methods in underground engineering risk identification. This paper proposes a new risk assessment method - Logical Arrangement Risk Evaluation (LARE), which combines the clearness of AHP in expressing index structure and the advantage of FTA in expressing logic.

LARE uses tree structure to express the model hierarchy, which is similar to AHP. However, the index nodes in LARE divide into the strong nodes (◇), common nodes (△) and weak nodes (○), which is different from AHP. The strong nodes can directly impact on the final risk status, which means there will be inevitable risks when such nodes emerge risks. The middle nodes are associated with itself risk levels. If the common node is in high level of risk, it will inevitably lead to the ultimate risk; but if the common node is in low risk level, it is only related to the risk status of upper node. The weak nodes only impact on the risk status. This design makes the better performance of the indexes influence on risk identification. For example, if the average temperature of the frozen soil deviates greater than the warning value, it indicates that this engineering is in the significant risk status and it is not necessary to analyze other risk factors.

There are logical terms to express the relationship between the nodes. Term "MAX" links to the strong nodes and output the maximum value. Term "Condition" links to the common nodes, which is a SIMO (Single Input Multiple Output) type, and the output will be the value of the risk level when it satisfies certain condition. Term "AVE" links to the weak nodes, and the output will be the weighted average of all inputs. Figure 1 shows the logical arrangement of Liquid nitrogen freezing method for risk identification. Where, C1 is water content, C2 is the salt content, C3 is the velocity of underground hydrodynamic flow, C4 is the maximum distance deviation of the final hole, C5 is the temperature deviation of the pipe tail, C6 is the deviation of liquid nitrogen quantity, C7 is the average temperature deviation of the frozen earth, C8 is the time formula for the liquid nitrogen to active freeze, C9 is the interface temperature formula of frozen earth continuous wall, and C10 is the highest temperature of he measured holes.

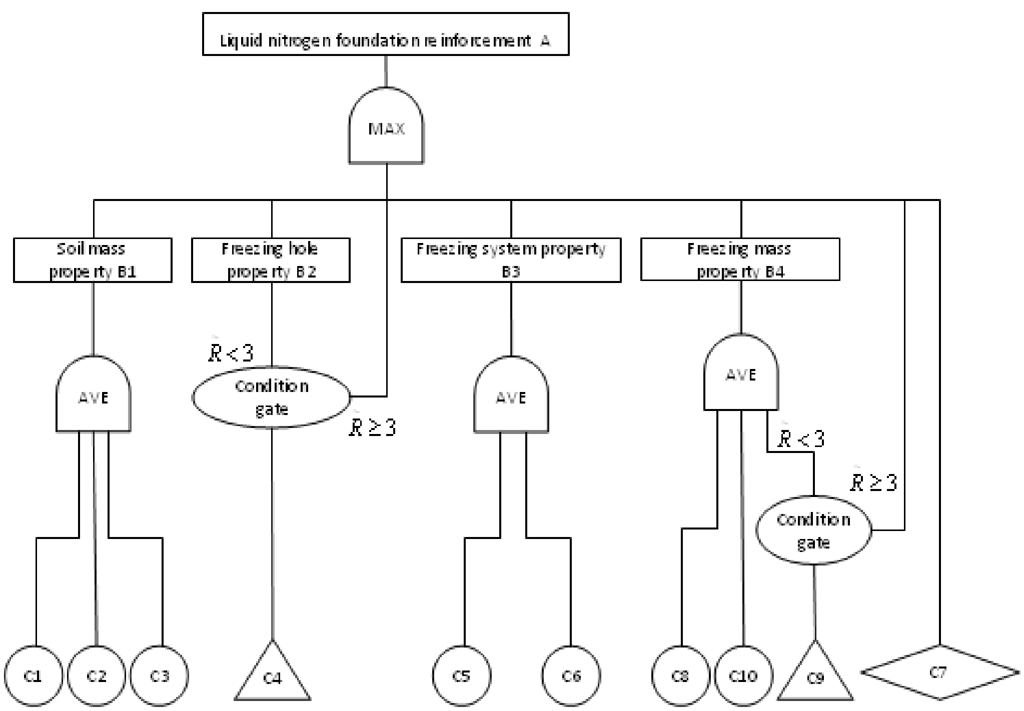

Figure1. LARE structure of Liquid nitrogen freezing method

B. Improved Clonal Selection Algorithm (ICSA)

Regular risk analysis methods are based on the risk factors already known, however the signs of risk for underground works is usually unknown previously. This paper intends to provide a new risk sign finding method by intelligent algorithms instead of existing knowledge of risk estimation knowledge. As the probability of accidents in underground projects is tiny, and algorithms like neural networks those require large amounts of historical data are not quite suitable. Biologic immune system can not only quick response to the intruder appeared before but also detects new invaders by its negative selection mechanism. Therefore, this paper integrates the "negative selection" and "clonal selection" mechanism of immune system, and introduces the dynamic clonal selection model in theoretical biological immunology to design the Improved Clonal Selection Algorithm (ICSA), which can reduce the rate of false alarm and the rate of missing report.

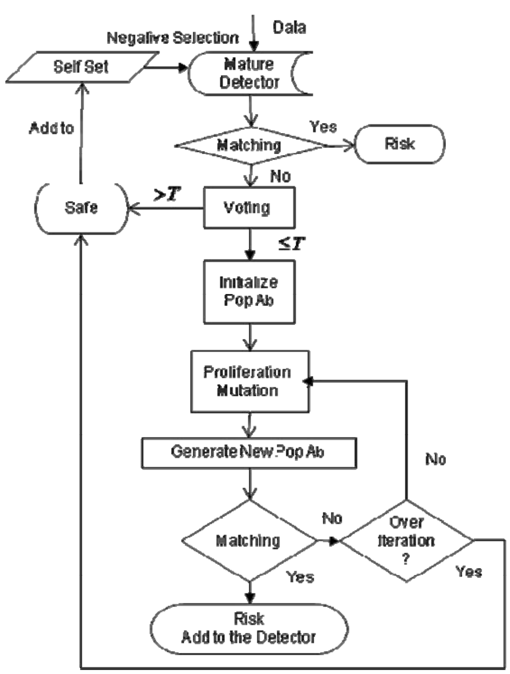

Figure2. ICSA algorithm flow

ICSA defines the non-risky data under safe engineering as self-set, and generated initial antibodies by negative selection. The initial antibodies are put into the mature detector set. If the current engineering data are matched to the antibodies in the detector, that means the engineering exists risk; otherwise the data will be changed into the voting process. If the number of safety is greater than the threshold value T, it means the project is safe and the new data will be added to self se, otherwise the current project is risky.

During the iteration, ISCA makes use of the dynamic clonal selection model for the population size calculation, proliferation and mutation of the antibody. The algorithm retains the excellent antibodies and abandons the inferior ones so as to compress the population of antibody. The algorithm flow of ICSA is shown as figure 2.

III. INFORMATION FLOW DESIGN

Tunneling projects usually have different processes and technics in different projects. In order to adapt the different processes risk management, the information systems abstracts all kind of working processes and technologies into a public processing program. Information input/output of various functions can be displayed and ran individually through this public processing system under different situation. And the system will also search indexes related to risk identification and extract the information automatically according to different processes and technics. The database include processes table, techniques table, observation terms table, formula table and data tables. These tables are interrelated to each other as figure 3.

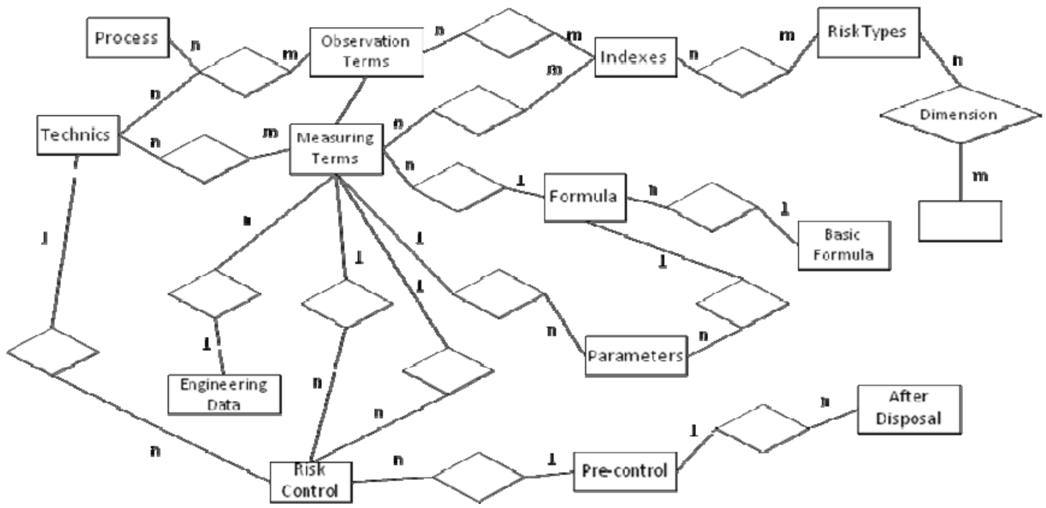

Figure3. Classification and extraction of information

According to the process of tunnel construction, the tunnel construction project is divided into 12 processes, which enable every processes are functional related but logically independent and integrated into a set of operations. Table 1 lists the available working process and related techniques.

The public processing system links to the current process and generates different information input and output processes according to different needs. When new function is added, the system will combine the related data categories and form a new process. The combination will be recorded and the code name will transfer to public processing system as a parameter. And then the information obtained will be stored or displayed (figure 4).

TABLE I. TECHNICS FOR TUNNELING BREAK-IN AND BREAK-OUT STAGE

No.	Process	Optional technics		
1	Break-out foundation reinforcement	Saline freezing method	Liquid nitrogen freezing method	Mixing pile method
		Jet grouting pile method	Dewatering method	SMW
2	Break-out base installment	Base installment		
3	Back support	Back support		
4	Break-out portal part explode	Break-out portal part explode		
5	Minus-circled flake assembling	Open loop	Closed loop	
6	Break-out propulsion	Slurry pressure balance	Earth pressure balance	
7	Break-out plugging	Break-out plugging		
8	Break-in foundation reinforcement	Same as break-out foundation reinforcement		
9	Break-in portal part explode	Break-in portal part explode		
10	Break-in propulsion	Slurry pressure balance	Earth pressure balance	
11	Break-in base installment	base installment		
12	Break-in plugging	Break-in plugging		

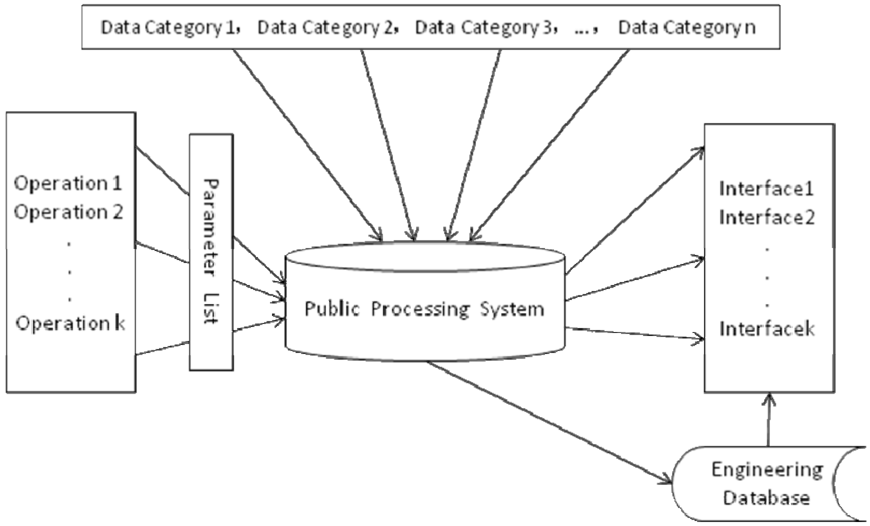

Figure4. Information flow relationship diagram

IV. 3. INFORMATION SYSTEM DESIGN

Underground project risk management involves the risk definition, risk monitoring, risk identification, risk estimation, risk analysis, risk assessment, risk alarming, risk pre-control and risk disposal these eight processes. In order to reach the goal of overall risk management, the design of the system mainly focuses on the relationship between each process. Figure 5 is the flowchart of the system.

Information which obtained from videos, reports, and automatic data collection are used to reflect the whole picture of the project and prevent information distortion. Considering the conditions of getting raw data are different under different processes and projects, the system establishes various models, including the Logical Arrangement Risk Evaluation (LARE) method, improved clonal selection algorithm (ICSA) etc for diversified risk identifications. Then the system will analyze the risk type, forecast the possible consequences of and evaluate the alarming level referring to the risk matrix to achieve multi-way risk alarming. The purpose of risk management system is to prevent accidents, so the system also carries out relevant risk analysis and find the related risk factors by backward reasoning mechanism. It also selects the appropriate pre-control or disposal measures basing on the emergency decision-making model to reduce the risks.

As the tunneling projects are usually in different geographical districts, the system takes advantage of the convenience of the Internet and GSM communication technology. And system software and hardware are arranged in the distributed topological structure according to characteristics of different roles (engineers, project managers, experts) (Figure 6).

In addition to collecting and analyzing data in the local engineering database, the system also synchronize with database in the remote server through the Internet. As risk definition and model establishment require professional knowledge, these function modules are set at the server. The experts operate through and the result will return to the site simultaneously. Taking the data security into account, the system establishes a virtual private network (VPN) and keeps all the parties in touch through a special encryption communication protocol to ensure information security and accessibility.

As risk management is accomplished by the technicians and engineering management, risk analysis, risk pre-control and risk disposal these three modules will be shared module for the two roles to use. Meanwhile, as time is a very key factor for risk management, both internet and GSM is used for risk alarm operation.

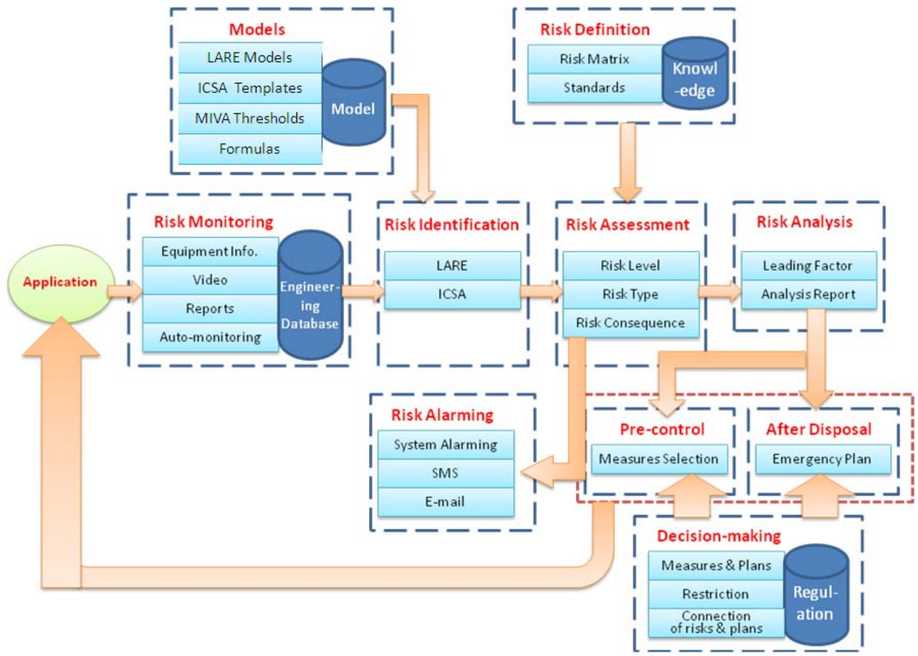

Figure5. Flowchart of risk management system

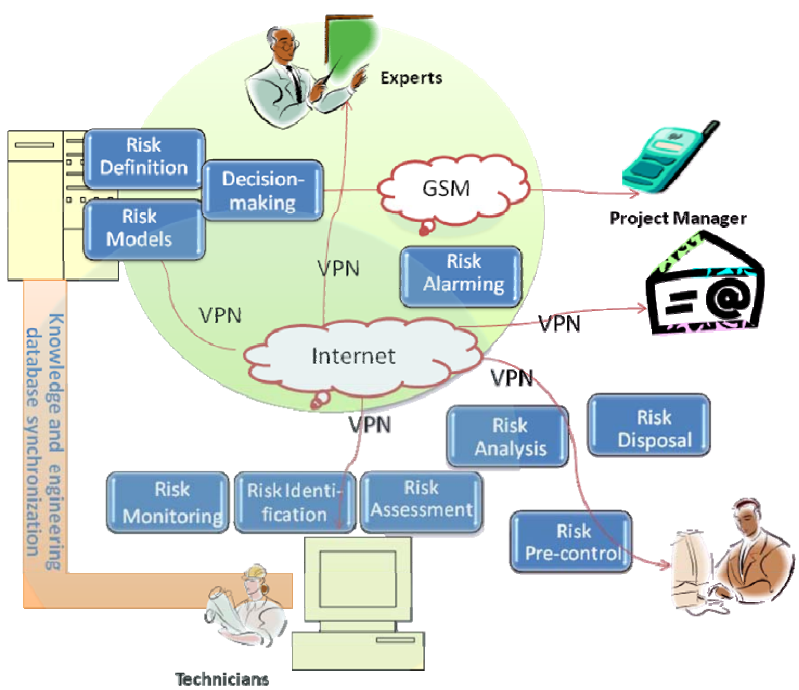

Figure6. Topology map of the system

V. 4. APPLICATION

Shield tunneling construction risk management system has been applied in different projects.

A. *Shanghai Metro Tunneling Project*

The System is used in the Jiangsu Road to Huashan Road region of Shanghai Metro Line 11, and the earth pressure balance shield start from the middle of Huashan Road and break-in at the south of Jiangsu Road. The down line break-in hole at Jiangsu Road will cross complex pipeline, including 2m long ultra-high voltage cable Φ 2400 storm sewer (near the ground walls), and the shield well only 12.5m away from Metro Line 2. Restricted to the environmental conditions, the downline chose the closed break-in method. And the reinforcement of the Φ 1200 jet grouting pile is also ahead of the excavation foundation pit, shown as figure 7.

The shield prepared breaking into the shaft of Jiangsu Road Station on August 24, 2009. And figure 8 gives the assessment result by using LARE on August 26, 2009.

As Shown in figure 8, the current risk is level M alert. And the risk analysis report informed that the excavation speed is too high, the cutter torque is low and reinforcement intensity is also too high.

Therefore, the risk pre-control module was activated and chose two - liquid injection to reinforce around the hole as pre-control measure through human-computer interaction. Then level M alarm is dropped to level N within safety. Finally the shield entered into the smoothly into the receiving shaft at Huashan Road Huashan Road successfully. The system not only identified the risk area but also proposed risk control measure to the technician for quick response and ensured the successful break-in.

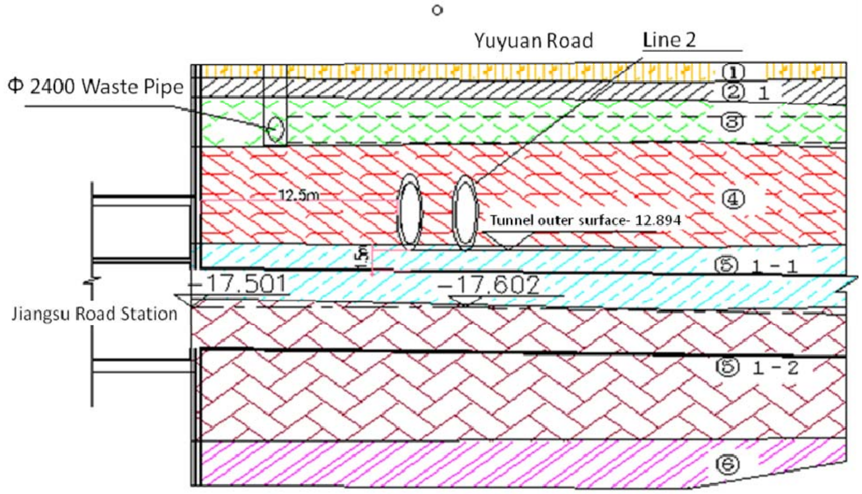

Figure7. Soil section of break-in hole at Jiangsu Road Station

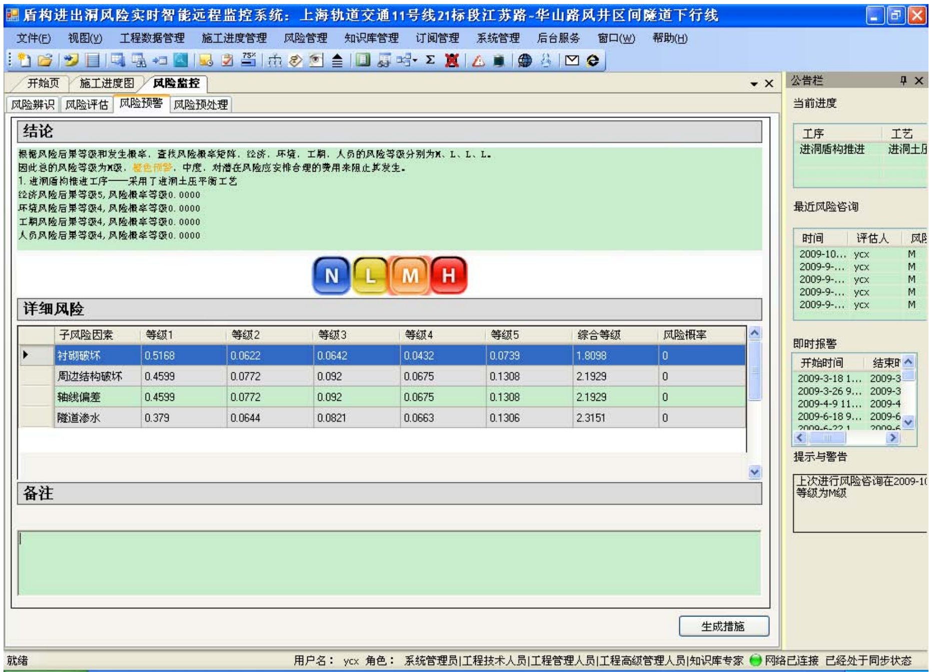

Figure8. Risk assessment result by LARE

B. Shanghai Yangtze River Tunneling Project

Shanghai Yangtze River Tunneling Project start from Wuhaogou in the Pudong New Area, crossing the water area of the South Harbor and landed in the south-west of Changxing Island and the total length is 8.95 km. the outer tunnel diameter is Φ 1500 cm and the inner diameter is 1370 cm. This project chose slurry air-ejecting balance shield to excavate. It sets up open wide broken rectangular concealed segment and 22m*48m *25 m working wells both at Changxing Island and Pudong. The Changxing Island reinforce area mainly adopted mixing pile method, ranged 16m from the shield excavation axis, shield section extended 3m outward and 25m in depth. Range 500mm from the shield well underground continuous wall used jet grouting pile method. And the shield machine entered the reinforce area according to certain uphill angle. In order to detect potential risks in time, 6 observation spots (Figure 9) were set up near the reinforce area to measure inclination and pore water pressure: 1＃ and 2＃ monitored inclination and layered settlement（both collected automatically）; 3＃与 4＃ monitored inclination、layered settlement, earth and water pressure, and 5＃and 6＃ monitored layered settlement, earth and water pressure.

As Figure 10 shows, the shield machine entered into break-in stage on May 13, 2008, and at 14 o'clock on the May 15, the system with ICSA model for real-time analysis displayed risk warning frequently. Subsequently, after the investigation and analysis, technicians found that there is some problems in the reinforced area. Therefore, speed of the shield machine and the quantity of soil must be controlled to avoid "over-excavation" and reduce disturbance and destruction for the reinforced soil. At last, the shield machine broke in the shaft successfully.

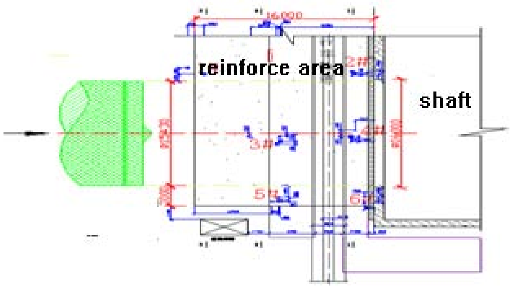

Figure9. Plan of Break-in Shaft

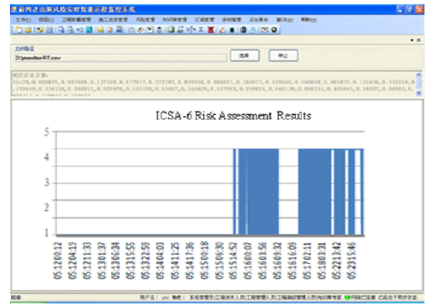

Figure10. ICSA risk assessment result

VI. CONCLUSION

The dynamic intelligent system for whole processes shield tunneling project risk management range from the definition of risk, risk monitoring, risk identification, risk assessment, risk analysis to risk disposal to complete the overall management for the whole construction process. According to the features of the underground projects, the Logical Arrangement Risk Evaluation (LARE) method and the improved clonal selection algorithm (ICSA) have been proposed, which proved effective in improving the efficiency and accuracy of risk identification and in engineering applications has been proven. With the development of information technologies and artificial intelligence, more advanced technologies in these two fields will be introduced to the project risk management.

ACKNOWLEDGEMENTS

This research is supported by Natural Science Foundation of China (NFSC) under Grant No. 50778109

REFERENCES

[1] The British Tunneling Society. The association of British Insurers:Joint code of practice for risk assessment of tunnel works in the UK–09[Z].2003.

[2] Eskesn S D.Tengborg P.Kampmann J et al. Guidelines for tunneling risk management:international tunneling association working group No.2[J].Tunneling and Underground Space Technology. 2004.19(3)pp217–237.

[3] The International Tunneling Insurance Group. A code of practice for risk management of tunnel works[S].2006.

[4] Ministry of Construction P.R.China. Guideline of Risk Management in Construction of Subway and Underground Works [S]. 2007.

[5] Chungsik Yoo. Young-Woo Jeon. Byoung-Suk Choi. IT-based tunnelling risk management system (IT-TURISK) – Development and implementation. Tunnelling and Underground Space Technology 2006 (21)pp 190–202

[6] GDMS(Geodata master system) : an information system for managing geoengineering projects[OL].http : //www.geodata.it.

[7] Huang Hongwei.Zeng ming.Chen Liang.Hu Qunfang. Risk Management Software (TRM1.0) Based on Risk Database for Shield Tunneling [J] development. Chinese Journal of Underground Space and Engineering. 2006. 2(1) pp36-41.

[8] Zhou Wenbo.Hu Min. Design and application of intelligent management system of digitalized construction in a shield-driven tunnel. Chinese journal of rock mechanics and engineering 2004.23(Z2)

[9] Zhou Dawei. Wu Gengfeng.Hu Min.An improved immune clonal selection algorithm [J].Computer Engineering.2009(11)

[10] Tang Xuan.Wu Huiming.Hu Min. Design and Development of Risk Management System of Shield Tunnelling [J]. Underground Engineering and Tunnels. 2006(4) pP20-24