Research on dynamic risk identification model of shield tunnelling based on REASON model

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Abstract

Aiming at the dynamic risk identification problem in shield tunnelling, and with the lack of research on dynamic risk identification theory and human factors in shield tunnelling, an analysis model of shield tunnelling based on REASON model has been proposed to establish in this paper. Relying on the fault tree theory and the model that established, the accident rule base has been built. After forming the REASON model into a network, the dynamic risk identification model for shield tunnelling has been built to provide theoretical guidance for dynamic risk management during the construction.

Keywords: Shield tunnelling, REASON model, dynamic risk identification model, risk management

1 Introduction

With the accelerating of urbanization process in china, urban population is expanding rapidly and land resources are becoming scarce. In addition, the conflict between the growing traffic demand and the increasing congestion of urban ground traffic has become particularly sharp. Aiming at this, development and utilization of city underground space has become an inevitable trend and an important means. By the end of 2013, metro has been operated in more than 19 cities in Chinese, and the total mileage has been up to 2366 KM [1]. The metro construction projects are in a stage of rapid development in scale and quantity, as shown in figure 1.

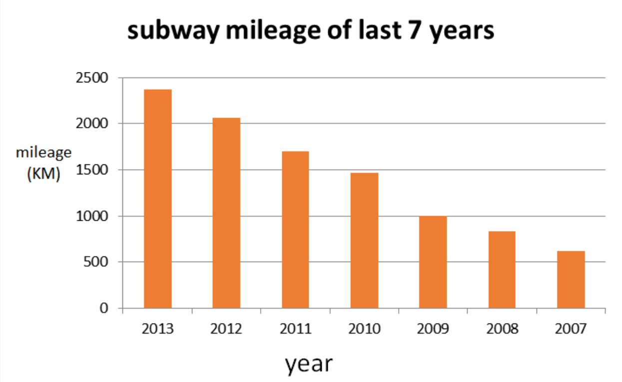

FIGURE 1 Statistics of metro mileage in last 7 years in China

According to the statistics, 88% of the accidents in the metro construction process are caused by unsafe behaviour of human, 10% are caused by the effect of both unsafe behaviour of human and material insecurity status, only about 2% are caused by non-human factors. Also, most of the accidents that caused by unsafe behaviour of human are due to the fault of construction management [2-3].

Although, some progress has been get aiming at the problems of safety management, problems are still existed as followed:

(1) Research on risk assessment and management in shield tunnelling is still concentrated in the aspects of overall risk evaluation and reliability calculation, which is lacking for dynamic risk assessment and has not, formed a set of management system. In addition, the achievements are out of practice, which cannot be used in practical projects.

(2) As the lack of theory research on human factors, importance is also lacking in practical projects, and deeply, the potential organizational factors that affect human behaviour have been ignored.

Therefore, in view of the questions above, research on risk analysis and risk identification of shield tunnelling has become increasingly urgent. Based on the risk identification of shield tunnelling, deeply influence of organizational factors on human has been analysed in this paper. By researching on the dynamic risk management theory from systematic perspective, the objective that improving management efficiency, avoiding engineering risk and improving economic benefit should be realized.

2 REASON model

REASON model is a conceptual model that proposed in a book called “Human error” by James Reason, who is a professor in University of Manchester. The core innovation point of this model lies in that from the perspective of system theory, unsafe behaviour of human and its potential organizational effect factors have been

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analysed. In the view of direct and indirect impact among managers, stakeholders and corporate culture, the perspective of accident analysis has been all-round expanded, and also all the relevant factors have been catenated by a logical accident chain reaction [4-5].

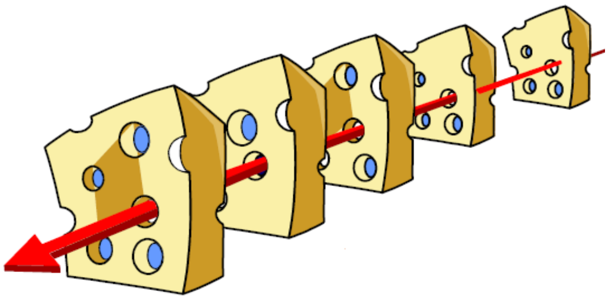

FIGURE 2 Original Reason Model

The original REASON model that shown in fig.2 includes the following aspects of meaning:

(1) As each piece of cheese represents an event, every hole of the cheese means a failure point. When a straight light can pass all cheese through the holes, accidents will occur.

(2) As long as moving a piece of cheese, that makes the light cannot penetrate, the accident can avoid.

(3) The model emphasizes the overall crash prevention ability of the organization. The core of the model is how to minimize the cost of management for maximum benefits, which means just prevent an accident from a piece of cheese, rather than for all defects of every piece of cheese.

After the proposing of REASON model, the model has been appropriate revised by researchers from various fields, such as man-machine engineering, medicine, nuclear industry, and aviation, marine, in order to reduce accidents. Up to now, many revising models have been proposed which control the occurring of accident effectively [6-7].

The introduction of REASON model into shield tunnelling safety management can help to establish the risk analysis model and find the fault chain for effectively prevention of accidents. But, because of the limitations of traditional REASOM model and the improving models, the application of them in shield tunnelling risk management still exist following problems and should be improved.

(1) Limited by researcher's field, the application field of existing improving reason model is also limited and may not applicable for other fields. Aiming at the complexity, maintainability and multi management system of shield tunnelling, the model must be improved particularly.

(2) The internal logic of REASON model shows that, accidents may happen when a straight light can pass all cheese through the holes. But in shield tunnelling projects, vulnerability can even cause an accident which may bring huge loss.

3 REASON model of shield tunnelling

3.1 HIERARCHY OF THE MODEL

The improved shield construction REASON model is consist of six layers, like planning and decision layer, safety supervision layer, organization management layer, dangerous premise layer, unsafe behaviour layer and the recovery layer. Among of the six layers, the human error of planning and decision layer, the safety supervision layer, and the organization management layer will not directly lead to risk events, and these layers belong to invisible factors level. The dangerous premise layer includes the self-situation of construction operations staff, as well as environmental factors, the failure of which may directly lead to risk events. Therefore, the dangerous premise layer is part of semi dominant factors. Unsafe behaviour layer and the recovery layer are belonging to the dominant factors level. Each level is described as follows.

(1) Planning and decision layer

Risk has already existing when a shield tunnelling project is in the stage of planning and design. For example, the place and method that chosen to construct the tunnel may potential influence on tunnelling construction. Generally speaking, the human errors of this layer contain programming errors, design failure, major decision errors, the fail subject of which are management departments and design departments.

(2) Organization and management layer

The most harmful errors are the invisible errors that latent and far from accidents, which usually exist in the organization and management of construction. When the behaviour that may bring about accidents is not existing, failure of the management layer will not make a threat of construction safe, which cannot be found easily. The organization and management layer mainly includes the company culture, organization structure, drawings, construction scheme, training management, operation management and resource management.

(3) Safety supervision layer

Safety supervision layer mainly emphasizes on safety supervision in the process of construction, which includes controlling and managing persons on site in the construction unit, monitoring unit's daily supervision, construct unit and all kinds of inspection of higher competent department. The human errors of this layer are mainly divided into four aspects: improper supervision plan, inadequate supervision, uncorrected known problems and supervision violations.

(4) Dangerous premise layer

Dangerous premise layer is made up of self-situation of construction operations staff, construction environment and equipment safety situation. Self-situation of construction operations staff includes psychological, physiological, skills, knowledge of line workers.

(5) Unsafe behaviour layer

Unsafe acts mainly refer to the direct behaviour that line workers done to cause accidents. It is consist of fault and illegal.

Fault is an unintentional behaviour, which means the inappropriate behaviour of line workers that deviated from willingness or construction scheme. Fault mainly includes four kinds of error: perceptual error, memory error, decision-making error and skill error.

Illegal means the violation of rules and operating procedures. It mainly contains intentional violation and unintentional violation. The unintentional violation is generally happens in the case of unfamiliar with the regulations, but the intentional violation happens in the case of that line workers know clearly that their operation is inconsistent with the rules and procedures.

(6) The defence and recovery layer

This layer is mainly means the measures after the risk factors are found unsafe.

As mentioned above, the improving shield construction REASON model as follows.

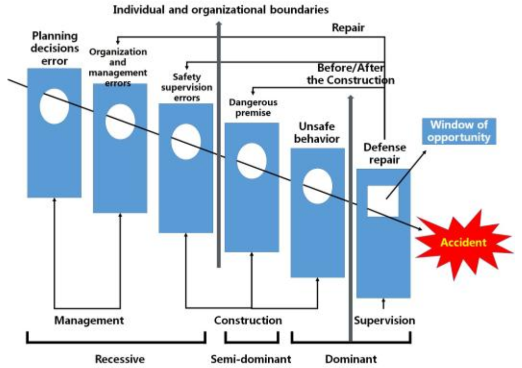

FIGURE 3 The improving REASON model of shield tunnelling

3.2 HIERARCHY OF THE MODEL

3.2.1 Common accident statistics of shield tunnelling

As Shield tunnelling construction system is composed of geology, shield machine and human, the shield tunnelling accidents are caused by geological, machine and man-made reasons. From the statistics, the major accident categories are shown as following table.

TABLE 1 Common accidents of shield tunnelling

No.	Name of the accident	No.	Name of the accident
1	TBM broken parts	11	Floating of tunnel
2	Damage of shield cutter	12	Twist of TBM
3	Mud cake	13	Gush
4	Fracture of jack	14	Overrun of boring deviation
5	Fracture of lifting head of segment installation	15	Starting plunge of TBM
6	Clogged pipeline	16	Segment broken
7	Accidents of circuit and pipeline	17	Jam of TBM
8	Subsidence and uplift of ground	18	Fires
9	Tilt and damage of house	19	Personal injury accident
10	Gushing of water and sand		

3.2.2 Risk identification of shield tunnelling

The way used to identify the risk of shield tunnelling construction in this paper is a method that combines work breakdown structure method and risk breakdown structure method.

(1) Analysis of shield construction process

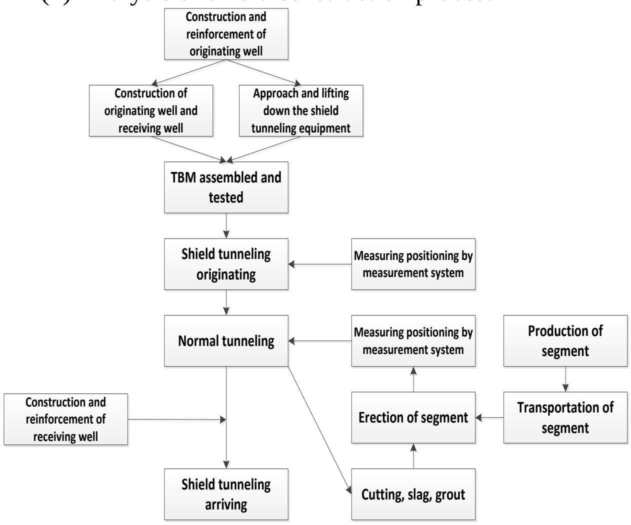

FIGURE 4 Major processing flow of shield tunnelling

(2) Overall risk analysis

According to the scope of this paper and the shield main flow, the overall risk has been analysed as shown in table2.

TABLE 2 Main analyses of risk identification in shield tunnelling

	Environment
Technical risks	Construction Preparation, Shaft Construction, Measurement, Shield Tunnelling, Earthwork Cutting, Slag, Segment Erection, Simultaneous Grouting, Secondary Grouting, Waterproofing And Drainage, Originating, Arriving, Lifting
Geological risks	Across the Rivers, Formation Empty, Quicksand, Gas Layer
Natural risks	Earthquake, Cold, Typhoon, Rainstorm, Flood
Surrounding Environmental risks	Nearby Buildings, Obstructions Within The Formation, Pipeline, Nearby Existing Traffic
Management and Organization risks	Construction Organization, Construction Personnel Management, Device Management, Fire Management

(3) Specific risk analysis

Based on general analysis, the 185 risk factors of shield construction are analysed by the way of list.

3.2.3 Elements extraction

Aiming at the demand of risk management in shield tunnelling, combined with the analysis of risk factors, the elements of the model have been extracted as shown in figure 5.

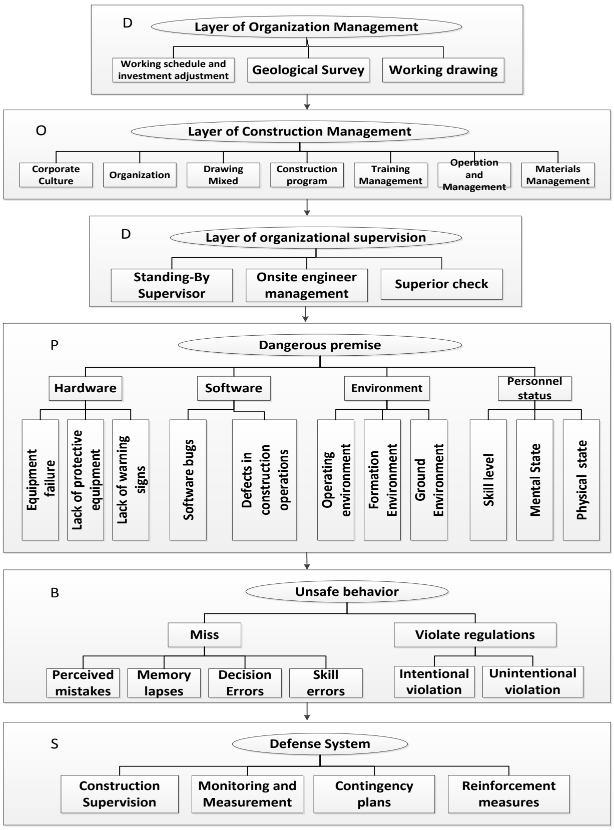

FIGURE 5 Elements system of Reason Model in shield tunnelling

3.3 ACCIDENT CAUSATION RULE BASE BASED ON FAULT TREE

There is a great number of factors that can affect shield tunnelling safety, the relative importance of which may changes at different time.In order to discern the pattern of tunnelling accidents from a overall perspective, fault trees of shield tunnelling have been built, which can not only arrange the relationship among the factors, but also help to set up an accident causation rule base as shown in figure 6.

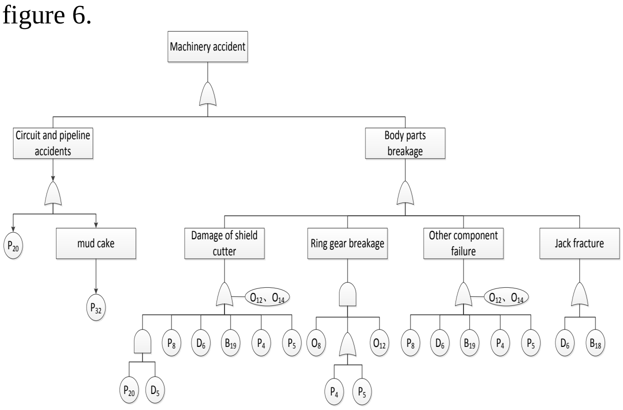

FIGURE 6 Event tree of mechanical failure

4 Dynamic risk identification of shield tunnelling

4.1 NETWORK DESCRIPTION OF REASON MODEL

4.1.1 Basic definitions and assume

Hypothesis 1: The network consists of the risk factors (node) and their relationship (side) of REASON model.

Hypothesis 2: System topology is fixed.

Definition 1 Node v: Suppose a point v∈V(G), v={0U1|P, C, H}, V contains only two kinds of status: 0 or 1, and v contains three properties: p(failure rate), c(loss degree), and H(Human factor). Then V is called a node. Set of nodes is V (G). Nodes have two types, called conditional node and unconditional node, as shown in figure 7.

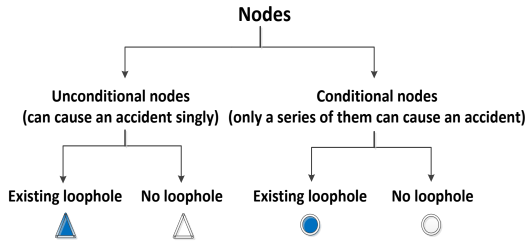

FIGURE 7 Classification of the nodes

Definition 2 Failure rate p: It is the description of the existence probability of loopholes in the nodes of the network.

Definition 3 loss degree c: Description of the potential loss that the nodes may bring.

Definition 4 Human factor h: Description of the influence degree that human state may affect the node status.

Definition 5 Interaction relationship e: Assuming that any direction line segment e=(u, v), in which u, v∈V(G),u≠v; e is named interaction relations, means elements u, v can simultaneously have an effect on some others. The set of mutual relations is L(G).

Definition 6 cause relationship f: Sets the direction line f=(u→v),u, v∈V(G), u≠v, calling f cause relationship, means U occurs will lead to v. The set of cause relationship is F(G).

Definition 7 Domain G_i: Assume G_i={V_i (G), E_i (G), Fi (G)}; G_i is called a domain.

Definition 8 Set domain G: Assume G=[G_1,G_2,…G_n], G is called a set domain.

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4.1.2 REASON model network

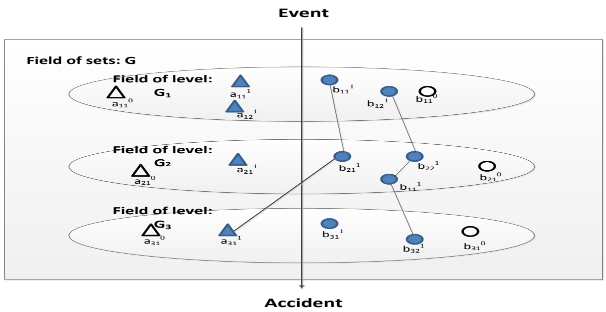

FIGURE 8 Schematic of network model of risk assessment in shield tunnelling based on Reason Model

(1) Risk factors constitute the basic unit of the model is divided into elements and no loopholes exist two types of vulnerability factors. With solid point vij and hollow point v'_{ij} said,(i=1,2…n, j=1,2…m), $v_{ij} \cup v'_{ij}=V(G)$;

(2) Elements can be composed according to certain rules of multiple domains represent different management levels. G_1, G_2,……G_n represent an elliptical area.

(3) Among the different elements of the same domain and different domains, there are two kinds of relationships. Namely the interaction relations and cause relations, expressed in e_{ij}、f_{ij} respectively.

(4) Probability p elements in attribute changes between 0 and 1, 0 properties for solid, 1 attribute is hollow.

(5) G_1-G_n together constitute the domain security management feature set G, $V(G) \cup E(G) \cup F(G)=G$;

(6) When there is a T occurs, the events of the line across the G line may be a straight line, also possible tree bifurcate structure;

(7) Domain G_1 to G_n all within the G movement according to certain rule, T intersection with the event circumstances exist that may occur during the movement. The law of the domain and the event T intersection of influenced by the interaction and cause relationship.

(8) For the occurrence of any event, hen the intersection of the event elements and fields are holes will lead to accidents. Assume $v_i^*=T \cap G_i$. If $v^*=\{v_1^*,v_2^* \ldots v_n^*\} \neq \emptyset$, and $\forall v_i^* \in v^*$, $\exists v'_{ij} \in G_i$, $v'_{ij}= v_i^*$, and accidents $A \neq \emptyset$.

4.2 DYNAMIC RISK IDENTIFICATION MODEL

The realization logical of the model is that when an event occurs, elements vulnerabilities are identified according to the order of the domain layer. Identification procedure is as follows:

Step1: Recognizing the loopholes of unconditional nodes in the first layer one by one, if existing, making a record and go on, if not existing or all nodes have been checked, go to next step.

Step2: Recognizing the loopholes of conditional nodes in the first layer, if existing, based on the relationship between the interaction relations and cause to track identification, identify vulnerabilities propagation path, skip to Step3; If not present, then the layer marked as safe, vulnerability factors attributes also change accordingly, and then jump to the Step4.

Step3: Contrasting identifies vulnerabilities and incidents caused by the propagation path of the rule base, if matched, and then there might be an accident, if not match, then safety.

Step4: Cycling step1, step2, and then the remaining layers sequentially domain identification, if the layers are marked as safe, then the overall safety.

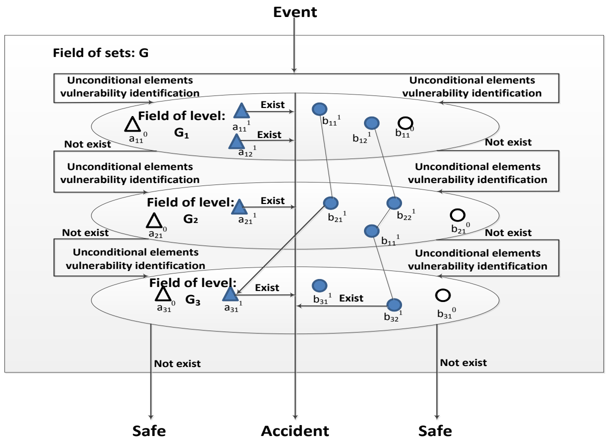

FIGURE 9 The logic of dynamic risk identification

5 Conclusions

Shield construction process is a complex system, which is more than one department, multidisciplinary, and multiple factors. And also risks exist in the dynamic changes which need to be dynamic and static analysis based on traditional risk assessment. Based on the traditional REASON model analysis, combined with the characteristics and risk factors shield construction accident itself, to establish a shield construction REASON mode, and model layers of elements were extracted; On the basis of the REASON network model described in the proposed shield construction dynamic risk identification model to provide theoretical guidance for identifying dynamic risk shield of the construction process.

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