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Study on Security Management System of Construction Enterprises in Evaluation and Pre-alarm According to Extension Theory

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Abstract: Safety is the most important problem to construction enterprises and the influent factors about safety are too many and complicated. Considering that the safety problems of construction enterprise are difficult to determine promptly and intuitively by current safety management evaluation methods, extension theory was used to study security management evaluate and warning system of construction enterprises in this study. Firstly, based of construction safety inspection experiences, security levels of construction are divided into four grades. Next, considering national construction security inspection standards as norms security management evaluation and warning system based of extension theory was established and the corresponding program was compiled also. To the non-safety project, its type of accident prone also was judged by extension theory. At last, this system was verified by an actual project and the results show that this method has practical and effective to the safety problem. In addition, this system can be used as references for enterprise security management.

Key words: Security management system, construction enterprises, extension theory, evaluate, pre-alarm

INTRODUCTION

Construction is a systematic engineering with many trades, processes following with cross-operations and continuous operations. In view of its complexities, many unsafe factors hided in the whole construction process and these factors may cause accidents at any time. Once accidents occurred, losses of lives and properties will inevitable. After November 2008, four billions were put into economic development of country and 66.5% investments were used for construction. However, safety accidents on construction keep higher in recent ten years through investigations of State Ministry of Housing (Wang, 2009). Therefore, facing such huge building tasks, national invests, people's lives and properties will be suffered greater threats by current safety management methods. So, it is urgent to strengthen safety management.

In recent years, many studies (Tam *et al*., 2002; Lu *et al*., 2003; Lin, 2008) about strengthen safety management in domestic were started and most methods judge construction safety by literal clauses instead of quantitative criteria. However, literal clauses are hard to accurately determine a project safe or unsafe and also can not timely make warning to unsafe project. So, security evaluation and warning of a construction project need a quantitative method to realize. Now research focus on security evaluation and warning area and around these many scholars research a lot. Common security evaluation methods include safety check list method, index evaluation method (Feng, 2008), probability risk evaluation method (Geng, 2010), analytic hierarchy process (Li *et al*., 2009), fuzzy risk evaluation (Mao, 2008), gray theory evaluation (Luo *et al*., 2010), application study of SVM evaluation (Sun and Li, 2010) and so on. These methods widely used in risk management, fault diagnosis, pattern recognition and so on. However, considered that security check data more, changes quick and influencing factors complicated, using those methods, construction security can not judge timely and accurately. The crucial problem is how to determine safe or not and security levels by simple method. To solve this problem, a new method-extension theory (Cai, 1994, 1999) was used in this study. In 1983, Caiwen put forward extension theory thinking of matter-element theory and extension set theory. The evaluated matter-element was judged through relevance of matter-elements, meanwhile evaluate and warning can also receive. In this study, this theory was used to establish the security management system of construction enterprises in evaluate and warning. This method can fully consider the reciprocal relations of influencing factors and satisfy provisions of

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construction safety inspection standards (Ministry of Construction Management Division, 2001). At last, some practical projects were adopted to verify the validity of this method. So, a new idea was provided to the construction enterprises' security management evaluate and warning.

SECURITY MANAGEMENT EVELUATION AND PRE-ALARM MODEL BASED OF EXTENSION THEORY

Extension theory: The core idea of extention theory is matter-element which can link essence and quantity of works. If it assumed that every evaluated matter-element R has n influencing factors (c_1, c_2,...,c_n) and every influencing factor has a corresponding magnitude (v_1, v_2,...,v_n). Then, matter-element R can be written as:

$$R=\begin{bmatrix} N, & c_1, & v_1 \\ & c_2, & v_2 \\ & \vdots & \vdots \\ & c_n, & v_n \end{bmatrix}=(N,c,v) \tag{1}$$

If every influencing factor has m related indicators, according to matter-element volatilization principle c_j can be expressed as cj-{c_{j1}, c_{j2}, c_{jm}}, among this -| means extension. Therefore, R = (N, c_{jk}, v_{jk}) (k = 1, 2,..., m) and the evaluated matter-element R can be written:

$$R=(N,C_j,V_j)=\begin{bmatrix} N, & c_1, & v_1 \\ & c_2, & v_2 \\ & \vdots & \vdots \\ & c_l, & v_l \end{bmatrix} \quad (j=1,2,\cdots,l;\, l=m\times n) \tag{2}$$

Every influencing factor has some range spaces which express section domain. So matter-element can be expressed as:

$$R_p=(N,C,V_p)=\begin{bmatrix} p, & c_1, & v_{p1} \\ & c_2, & v_{p2} \\ & \vdots & \vdots \\ & c_l, & v_{pl} \end{bmatrix}=\begin{bmatrix} p, & c_1, & \langle a_{p1},b_{p1}\rangle \\ & c_2, & \langle a_{p2},b_{p2}\rangle \\ & \vdots & \vdots \\ & c_l, & \langle a_{pl},b_{pl}\rangle \end{bmatrix} \tag{3}$$

where, $v_{pi} = \langle a_{pi}, b_{pi}\rangle$, is range of c_i.

According to a specific assessment standard, evaluation system was divide into s levels, then classical domain matter-element can be expressed as:

$$R_{0t}=(N_{0t},C,V_{0t})=\begin{bmatrix} N_{0t}, & c_1, & v_{0t1} \\ & c_2, & v_{0t2} \\ & \vdots & \vdots \\ & c_l, & v_{0tl} \end{bmatrix}=\begin{bmatrix} N_{0t}, & c_1, & \langle a_{0t1},b_{0t1}\rangle \\ & c_2, & \langle a_{0t2},b_{0t2}\rangle \\ & \vdots & \vdots \\ & c_l, & \langle a_{0tl},b_{0tl}\rangle \end{bmatrix}(t=1,2,\cdots,s) \tag{4}$$

where N_{0t} indicates types of evaluation; c_i indicates evaluation index (influencing factor); v_{0ii} expresses classical domain $\langle a_{0ii}, b_{0ii}\rangle$ which determined by N_{0t} corresponding c_i.

The assessment message to be evaluated matter element can be expressed as R_0:

$$R_0=(N_0,C,V_{0t})=\begin{bmatrix} N_0, & c_1, & v_1 \\ & c_2, & v_2 \\ & \vdots & \vdots \\ & c_l, & v_l \end{bmatrix} \tag{5}$$

where v_i express a specific value corresponding c_i.

Matter Element and its' section domain, classical domain were established by matter-element theory. How to evaluate matter element? Extension theory adopted method of correlation function to realize. Before evaluation, matter element must satisfy a necessary requirement which means value v_{ik} corresponding to influencing factor c_i meeting a specific condition. If value v_{ik} satisfy necessary requirement, evaluation began. Otherwise, evaluation stops. Based of extension theory, correlations of value v_{ik} were considered as judge foundation. Correlation functions can be determined by internal distance from value v_{ik}. Firstly, internal distance between value v_i and v_{oti} were written as:

$$\rho(v_i,v_{pi})=\left|v_i-\frac{a_{pi}+b_{pi}}{2}\right|-\frac{1}{2}\left(b_{pi}-a_{pi}\right)$$

$$\rho(v_t,v_{0ti})=\left|v_t-\frac{a_{0ti}+b_{0ti}}{2}\right|-\frac{1}{2}\left(b_{0ti}-a_{0ti}\right) \tag{6}$$

Then, correlation function $k_{ii(v)}$ about value v_i was established by extension theory:

$$k_{ti}(v_i)=-\frac{\rho(v_i,v_{0ti})}{|v_{0ti}|}\left(v_i\in v_{0ti}\right)$$

$$k_{ti}(v_i)=-\frac{\rho(v_i,v_{0ti})}{\rho(v_i,v_{pi})-\rho(v_i,v_{0ti})}\left(v_i\notin v_{0ti}\right) \tag{7}$$

Correlation function of ranks about evaluated matter element was expressed as:

$$k_t(N)=\sum_{i=1}^{l} w_i k_{ti}(v_i) \quad (t=1,2,\cdots,s;\, i=1,2,\cdots,l) \tag{8}$$

where, w_i indicates weighting distribution coefficient about index C_i. Selecting the maximum of $k_t(N)$, the location t_0 of maximum value indicate the rank of evaluated matter element:

$$k_{t0}(N) = \max\{k_t(N) | t = 1, 2, \cdots, s\} \quad (9)$$

Security management evaluation model: Security management on construction enterprises are directly expressed as a construction project security management which was the evaluated matter element. Its section domain and classical domain were determined by Construction Safety Inspection Standards which formulated by country. Based of this standard, the influencing factors of matter element have ten contents. The values from ten influencing factors were obtained by score of safety inspection. So matter element can be written as:

$$R = \begin{bmatrix} N & \text{Safety management} & v_1 \\ & \text{Civilized construction} & v_2 \\ & \text{Scaffold} & v_3 \\ & \text{Excavation and formwork engineering} & v_4 \\ & \text{Protection of three safeguards and four holes} & v_5 \\ & \text{Construction of electricity} & v_6 \\ & \text{Material hoist and topical elevator} & v_7 \\ & \text{Crane} & v_8 \\ & \text{Lifting} & v_9 \\ & \text{Construction equipment} & v_{10} \end{bmatrix}$$

After the evaluated matter element was determined, the classical domain and section domain can be obtained as follow. According to Construction Safety Inspection Standards which settled by country and experience of construction safety inspection and experience in construction safety inspection, security levels of construction are divided into four grades: Safety, safer, insecurity and serious insecurity. Then, the classical domain and section domain of the construction safety inspection will be expressed as:

Classical domain:

$$R_{01} = \begin{bmatrix} \text{Safety} & c_1 & \langle 9,10 \rangle \\ & c_2 & \langle 18,20 \rangle \\ & c_3 & \langle 9,10 \rangle \\ & c_4 & \langle 9,10 \rangle \\ & c_5 & \langle 9,10 \rangle \\ & c_6 & \langle 9,10 \rangle \\ & c_7 & \langle 9,10 \rangle \\ & c_8 & \langle 9,10 \rangle \\ & c_9 & \langle 4.5,5 \rangle \\ & c_{10} & \langle 4.5,5 \rangle \end{bmatrix} R_{02} = \begin{bmatrix} \text{Safer} & c_1 & \langle 8,9 \rangle \\ & c_2 & \langle 16,18 \rangle \\ & c_3 & \langle 8,9 \rangle \\ & c_4 & \langle 8,9 \rangle \\ & c_5 & \langle 8,9 \rangle \\ & c_6 & \langle 8,9 \rangle \\ & c_7 & \langle 8,9 \rangle \\ & c_8 & \langle 8,9 \rangle \\ & c_9 & \langle 4,4.5 \rangle \\ & c_{10} & \langle 4,4.5 \rangle \end{bmatrix}$$

$$R_{03} = \begin{bmatrix} \text{Insecurity} & c_1 & \langle 7.5,8 \rangle \\ & c_2 & \langle 15,16 \rangle \\ & c_3 & \langle 7.5,8 \rangle \\ & c_4 & \langle 7.5,8 \rangle \\ & c_5 & \langle 7.5,8 \rangle \\ & c_6 & \langle 7.5,8 \rangle \\ & c_7 & \langle 7.5,8 \rangle \\ & c_8 & \langle 7.5,8 \rangle \\ & c_9 & \langle 3.75,4 \rangle \\ & c_{10} & \langle 3.75,4 \rangle \end{bmatrix} R_{04} = \begin{bmatrix} \text{Serious insecurity} & c_1 & \langle 7,7.5 \rangle \\ & c_2 & \langle 14,15 \rangle \\ & c_3 & \langle 7,7.5 \rangle \\ & c_4 & \langle 7,7.5 \rangle \\ & c_5 & \langle 7,7.5 \rangle \\ & c_6 & \langle 7,7.5 \rangle \\ & c_7 & \langle 7,7.5 \rangle \\ & c_8 & \langle 7,7.5 \rangle \\ & c_9 & \langle 3.5,3.75 \rangle \\ & c_{10} & \langle 3.5,3.75 \rangle \end{bmatrix}$$

Section domain:

$$R = (p, C, V) = \begin{bmatrix} p & c_1 & \langle 6,10 \rangle \\ & c_2 & \langle 12,20 \rangle \\ & c_3 & \langle 6,10 \rangle \\ & c_4 & \langle 6,10 \rangle \\ & c_5 & \langle 6,10 \rangle \\ & c_6 & \langle 6,10 \rangle \\ & c_7 & \langle 6,10 \rangle \\ & c_8 & \langle 6,10 \rangle \\ & c_9 & \langle 3,5 \rangle \\ & c_{10} & \langle 3,5 \rangle \end{bmatrix}$$

Pre-alarm model: Safety management pre-alarm model of construction enterprise is similar to safety management evaluation model in the aspects of establish and analytic methods. According to Construction Safety Inspection Standards which settled by country and experience of construction safety inspection and experience in construction safety inspection, security levels of accident are divided into four grades: No warning, slight warning, mid warning, serious warning. Based of the main cause accidents, the classical domain and section domain of evaluated matter element will be obtained. High fall accident is the common accident. So, high fall accident is the study in this study. The evaluated matter element and its classical domain, section domain will be written as:

Evaluated matter element:

$$R = \begin{bmatrix} N & \text{Staff safety education} & v_1 \\ & \text{Protection of three safeguards and four holes} & v_2 \\ & \text{Scaffold} & v_3 \\ & \text{Formwork engineering} & v_4 \\ & \text{Construction machine} & v_5 \end{bmatrix}$$

Classical domain:

$$R_{01} = \begin{bmatrix} \text{No warning} & c_1 & \langle 1.6,2 \rangle \\ & c_2 & \langle 9,10 \rangle \\ & c_3 & \langle 4.5,5 \rangle \\ & c_4 & \langle 4.5,5 \rangle \\ & c_5 & \langle 9,10 \rangle \end{bmatrix} \quad R_{02} = \begin{bmatrix} \text{Slight warning} & c_1 & \langle 1.2,1.6 \rangle \\ & c_2 & \langle 7.5,9 \rangle \\ & c_3 & \langle 3.75,4.5 \rangle \\ & c_4 & \langle 3.75,4.5 \rangle \\ & c_5 & \langle 7.5,9 \rangle \end{bmatrix}$$

$$R_{03} = \begin{bmatrix} \text{Mid warning} & c_1 & \langle 1,1.2 \rangle \\ & c_2 & \langle 6,7.5 \rangle \\ & c_3 & \langle 3,3.75 \rangle \\ & c_4 & \langle 3,3.75 \rangle \\ & c_5 & \langle 6,7.5 \rangle \end{bmatrix} \quad R_{04} = \begin{bmatrix} \text{Serious warning} & c_1 & \langle 0.6,1 \rangle \\ & c_2 & \langle 3,6 \rangle \\ & c_3 & \langle 1.5,3 \rangle \\ & c_4 & \langle 1.5,3 \rangle \\ & c_5 & \langle 3,6 \rangle \end{bmatrix}$$

Section domain:

$$R = (p, C, V) = \begin{bmatrix} p & c_1 & \langle 0.5,2 \rangle \\ & c_2 & \langle 2.5,10 \rangle \\ & c_3 & \langle 1.25,5 \rangle \\ & c_4 & \langle 1.25,5 \rangle \\ & c_5 & \langle 2.5,10 \rangle \end{bmatrix}$$

Determination of evaluated matter element and Parameter value: The calculate process of safety management pre-alarm is similar to safety management evaluation and use extension theory to analyze matter-element when substitute Eq. 6-9, then can ensure the sort of accident.

According to extension theory and actual situation of security management of construction enterprise, established security management assessment of construction enterprise and warning model based of extension theory, the basic ideas of this model in analyze problem is expressed in Fig. 1.

The evaluated matter element R has ten factors which may not emerge simultaneously on some construction stage. For example, scaffold and crane can not occur on excavation stage. In this case, v_3 and v_8 will be removed from this evaluated matter element. At the same time, its classical domain, section domain will adjust also.

After the evaluated matter element was determined, preliminary safety case will implement before evaluation. Preliminary safety case based on Construction Safety Inspection Standards which consider that every factor among ten factors of safe score sheet must reach 70% of total score. On the contrary, this project is determined unsafe and the evaluation stops.

During safety inspection process no matter which one arises problems will serious threat project's safety, so every matter-element feature should be distribute same weight in practical application.

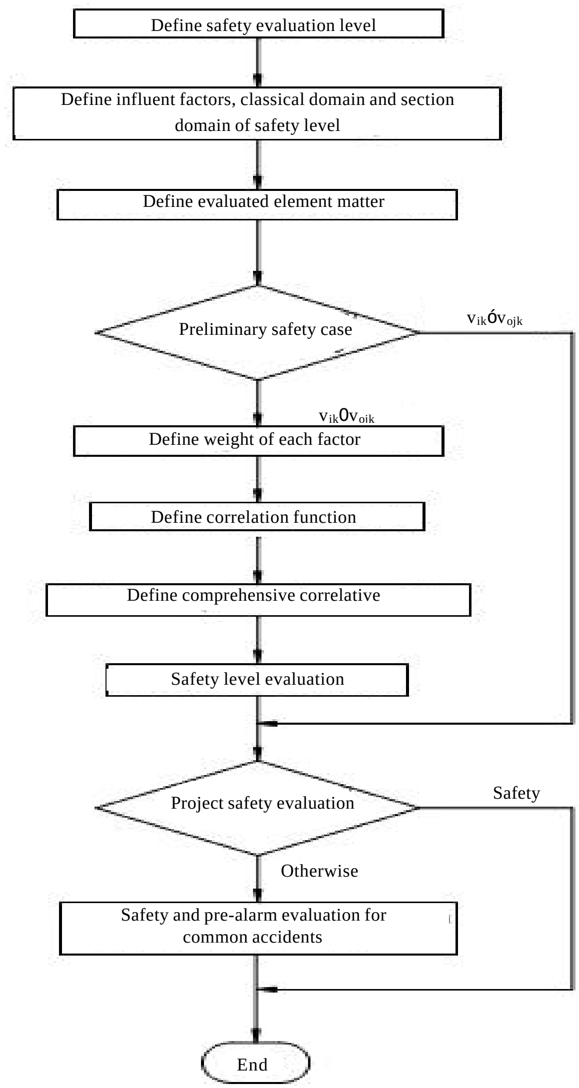

Fig. 1: Security management evaluation and pre-alarm system based on extension theory

PRACTICAL APPLICATION OF SECURITY MANAGEMENT EVALUATION AND PRE-ALARM

This is a safety inspection score table for practical project of a glass factory in Hebei province (Table 1) which according to Construction Safety Inspection Standards , is a inspection result about safety manager take safety inspection in one stage of construction process. Take safety evaluation for this project by the above theory.

This project only has seven basic features of matter-element in current inspection stage, therefore in the further calculation process only seven items among the

Table 1: Safety inspection score table

Items	Score
Safety management	8.10
Civilized construction	15.60
Scaffold	8.60
protection of three safeguards and four holes	8.40
Construction of electricity	8.50
Crane	9.90
Construction equipment	4.55

classical domain and section domain and no use of value about foundation pit and formwork engineering, material hoist and topical elevator, lifting erection.

Evaluated matter element:

$$R = \begin{bmatrix} N & \text{Safety management} & 8.1 \\ & \text{Civilized construction} & 15.6 \\ & \text{Scaffold} & 8.6 \\ & \text{Protection of three safeguards and four holes} & 8.4 \\ & \text{Construction of electricity} & 8.5 \\ & \text{Crane} & 8.5 \\ & \text{Construction equipment} & 4.55 \end{bmatrix}$$

Preliminary safety evaluation shows that every score of factors are all greater than 70% total score. So the project safety evaluation will continue in the future.

Correlation function: According to Eq. 6-8, the calculate process of correlation function $k_{11}(v_1)$ is:

$$k_{11}(v_1) = \frac{\rho(v_1, v_{011})}{\rho(v_1, v_{p1}) - \rho(v_1, v_{011})} = \frac{0.9}{-1.9 - 0.9} = -0.321$$

$$\rho(v_1, v_{p1}) = \left|8.1 - \frac{1}{2}(10+6)\right| - \frac{1}{2}(10-6) = -1.9$$

$$\rho(v_1, v_{011}) = \left|8.1 - \frac{1}{2}(10+9)\right| - \frac{1}{2}(10-9) = 0.9$$

The calculation of other correlation function is similar to above process, results as follows:

$k_{12}(v_1) = 0.056$, $k_{13}(v_1) = -0.05$, $k_{14}(v_1) = -0.24$, $k_{21}(v_2) = -0.4$, $k_{22}(v_2) = -0.4$, $k_{21}(v_2) = -0.1$, $k_{23}(v_2) = 0.125$, $k_{24}(v_2) = -0.143$, $k_{31}(v_3) = -0.22$, $k_{33}(v_3) = 0.4$, $k_{33}(v_3) = -0.3$, $k_{34}(v_3) = -0.44$, $k_{41}(v_4) = -0.273$, $k_{42}(v_4) = 0.33$, $k_{43}(v_4) = -0.2$, $k_{44}(v_4) = -0.36$, $k_{51}(v_5) = -0.25$, $k_{42}(v_5) = 0.5$, $k_{53}(v_5) = -0.25$, $k_{54}(v_5) = -0.4$, $k_{61}(v_6) = -0.25$, $k_{62}(v_6) = 0.5$, $k_{63}(v_6) = -0.25$, $k_{64}(v_6) = -0.4$, $k_{71}(v_7) = 0.125$, $k_{72}(v_7) = -0.1$, $k_{73}(v_7) = -0.55$, $k_{74}(v_7) = -0.64$

Safety evaluation: According to Eq. 9, the function about safety management evaluation can be calculated, it is:

$$K_{p1} = A_1 \times K_1 = \begin{bmatrix} 1/7 \\ 1/7 \\ 1/7 \\ 1/7 \\ 1/7 \\ 1/7 \\ 1/7 \end{bmatrix}^T \begin{bmatrix} -0.321 & 0.056 & -0.05 & -0.24 \\ -0.4 & -0.1 & 0.125 & -0.143 \\ -0.22 & 0.4 & -0.3 & -0.44 \\ -0.273 & 0.33 & -0.2 & -0.36 \\ -0.25 & 0.5 & -0.25 & -0.4 \\ -0.25 & 0.5 & -0.25 & -0.4 \\ 0.125 & -0.1 & -0.55 & -0.64 \end{bmatrix}$$
$$= [-0.227 \quad 0.227 \quad -0.211 \quad -0.375]$$

Based on the evaluation criterion, security level of this project is considered as "safer". A level of safer means exist potential safety hazard; it also means this project need to make safety evaluation about common accidents and strength prevention.

Pre-alarm of accident: High fall accident is the easiest incidence accident in all construction enterprise and formwork engineering no apparent in this project, so take safety evaluation aiming at high-altitude crash and define the classification of warning. Evaluating matter-element of this project is:

$$R = \begin{bmatrix} N & \text{staff safety education} & 2 \\ & \text{Safety protection of three treasuresand four openings} & 8.4 \\ & \text{Scaffold} & 4.3 \\ & \text{Construction machine} & 9.63 \end{bmatrix}$$

According to Eq. 6-9, correlation function about security management warning is:

$$K_{p1} = \begin{bmatrix} 0.25 \\ 0.25 \\ 0.25 \\ 0.25 \end{bmatrix}^T \begin{bmatrix} 0 & -0.444 & -0.767 & -0.667 \\ -0.273 & 0.6 & -0.794 & -0.6 \\ -0.222 & 0.4 & -0.811 & -0.65 \\ 0.37 & -0.315 & -0.825 & -0.726 \end{bmatrix}$$
$$= [-0.031 \quad 0.06 \quad -0.8 \quad -0.661]$$

From the analysis results: This project expresses "slight warning" for high-altitude crash. Therefore, this project should inspect and rectify in aspects that is easily happened high-altitude crash and made construction more security.

CONCLUSION

A system of construction enterprises in evaluation and pre-alarm based of extension theory was established. This system has two parts of security evaluation and pre-alarm. Firstly, if preliminary safety evaluation was qualified, the security management evaluation will continue. Next, if the security level of this project was “safety”, the evaluation will stop. Otherwise, pre-alarm of the incidence accident will be determined. After security evaluation and pre-alarm identification, the security of a project will be obtained. At the same time, the incidence accident will be received also. At last, the security of two practical projects was judged. This system can provide new idea for the security management of construction enterprises.

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