Study on Human Performance Reliability in Green Construction Engineering

Xiaoping Bai [a], Cheng Qian [b]

School of management, Xi'an University of Architecture and Technology, Xi'an 710055, China

[a]xxpp8899@126.com, [b]Qiancheng.qc@163.com

Abstract. The human reliability analysis in green construction has a great significance in safeguarding the quality and safety of the green construction. At first, this paper analyzes the factors affecting the human reliability in green construction, and looks the humans and their environment as a whole system to establish the single human reliability model based on the Markov chain analysis method. On this basis, a new human system reliability model and related process method based on integrated ant colony algorithm and network diagram for the whole green construction engineering is presented. The new model and method can help us to know the influence of green construction engineering management and the environment on human reliability and find the key factors to improve the reliability of the whole system.

Keywords: Green construction; human engineering; reliability; weight; network diagram.

1. Introduction

The construction phase is the key phase affecting the quality of architectural engineering. With the development of the technology and mechanization, the quality of construction has been greatly improved. But the construction accidents still happened frequently. It has been estimated that accidents caused by human error accounted for 65% of all unsafe incidents. Human has great impact on improving the quality of construction. Nowadays, most persons still focus on the economy of constructions and ignore the human performance reliability in the construction and the impact of construction on the environment.

In foreign, based on a classification system of human factors analysis method, J. W. Garrett proposes a new error analysis and classification method which can be used in the construction industry [1]. N. cLind puts forward three kinds of reliability model to analyze the influence of human error on the reliability of structure, which includes single error model, combined error model and error diffusion model [2]. Deepthi C. Epaarachechi has focused on the impact of human error on the structural parameters and established human error model based on the analysis of human reliability [3]. F. Vanderhaege has established several models and methods to analyze human error [4]. They believe that mistakes in managements have a significant impact on human error and put forward three main factors: factors to collecting information, factors to solving problems and factors to action.

In China, Shi Yufang defines the concept of the human reliability in construction system and uses the disjoint minimal path set algorithm to establish the human reliability model [5]. But it only considers the effect of resources, time and cost on the reliability, without considering the environment as well as the green construction environment. Yang Mingming analyzes the mechanism of human error and uses the Grey relational analysis method to get the importance degree of the factors affecting human reliability [6]. He establishes personnel reliability model based on theories of systems engineering, but ignores relationships of influence factors. Li Pengcheng, Dai Licao put forward a kind of organization oriented human error causal model [7]. Li Jianmin thinks that the accuracy of probability of factors caused accidents is related to the field observation data. In order to make the analysis result accord with actual, they use expert evaluation to improve the analysis method and build a model that contains a random factor [8]. Yan Xiao uses the fuzzy comprehensive evaluation model to evaluate green construction [9].

The analysis of human performance reliability has become an independent subject [10]. Based on theories of systems reliability, this paper analyzes some factors affecting human errors, and firstly uses Markova analysis method to establish the individual reliability model, and then also sets up a new human system reliability model of the whole green construction engineering based on integrated network analysis and ant colony algorithm. The new model can help us to know the influence of green construction management and the environment on human performance reliability and find the key factors to improve the reliability of the whole system.

2. Some factors affecting the human performance reliability in the green construction engineering

Human performance reliability refers to the success probability of the person's activities that must be completed for the system reliability and availability [11]. During construction, human performance reliability is affected by many factors, which can be classified into two categories including objective factors and subjective factors.

The objective factors generally include staff working environment and team coordination relationships. The staff working environment factors, e.g. Temperature, climate, noise and working time can influence the human performance reliability of the green construction, directly or indirectly. These factors will influence a person's judgment and cause people to make mistakes. Especially, working environment factors have important effects on the human performance reliability in green construction. The traditional human reliability method thinks that human reliability has exponentially increased with the growth of the working time [12] [13] [14]. Team coordination refers to the reasonable green construction management in this paper. Green construction management not only affects progress, quality, cost and environment, but also indirectly has an impact subjective factors which will lead to human errors. For example, unreasonable green construction management will have an impact on the environment and the Project duration, which will bring about constructor' stress and increase the probability of human error.

The subjective factors generally consist of physiological factors, psychological factors and personal skills. The subjective factors have a direct influence on constructor' reliability, for example, the fatigue, stress, et al, may give rise to human error and reduce the human reliability. Missing operation, wrong operation, not carrying out the protection of environment in the construction process in order to get more profit, will lead to unsafely accidents, for example, in 2009, the whole building that lay in Shanghai's Lotus Riverside community collapsed because the construction side use inferior materials and turn out substandard products.

3. The single construction human performance reliability model

To establish the individual reliability model based on Markova analysis method, this paper puts forward some hypothesis.

(1) This paper looks person and the environment as a system and considers five factors affecting the human performance reliability, such as the physiological factor, the psychological factor, personal skills, working environment and green construction management.

(2) The human error in each state is independent.

(3) The emergence of more than once transition probability in the interval of Δt can be ignored.

Some symbols used in single construction human performance reliability model are expressed as follows:

$P_i(t)$—The probability that a person is in the i state at time t.

u—the repair rate that person transfers from the unreliable state 11 to the reliable state 0.

λ_i—Human error rate in each state, $i = 1,2,3,4,5,6,7,8,9,10$.

h_i—The state transition probability that person transfers from the state of i to the unreliable state 11, $i = 1,2,3,4,5,6,7,8,9,10$.

i —The i state in the system.
i =0, the person is in normal working state.
i =1, the state that person is in a bad psychological state, but can work normally.
i =2, the state that person is in a bad physiological state, but can work normally.
i =3, the state that person don't have good personal skills, but can work normally.
i =4, the state that person is in a poor working environment, but can work normally.
i =5, the state that person is in a bad green construction management case, but can work normally.
i =6, the state that person is in a bad psychological state, but cannot work normally.
i =7, the state that person is in a bad physiological state, but cannot work normally.
i =8, the state that person don't have good personal skills, but cannot work normally.
i =9, the state that person is in a poor working environment, but cannot work normally.
i =10, the state that person is in a bad green construction management, but can work normally.
i =11, the state that person work in unreliable condition.

The probability that a person is in the 0 state during dt is:

$$P(0)=1-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10})dt \quad (1)$$

The once self-repair probability during dt is

$$P(11 \rightarrow 0) = u\,dt \quad (2)$$

The probability that person still in the state 0 during $t+dt$ is

$$P(t+dt) = P_{11}(t)udt + P_0(t) \left[1-(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10})dt\right] \quad (3)$$

From the above equation, we can get the following equation

$$\frac{dP_0(t)}{dt}+(\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6+\lambda_7+\lambda_8+\lambda_9+\lambda_{10})P_0(t)=uP_{11}(t) \quad (4)$$

The probability that person still in the state 1 during $t+dt$ is

$$\frac{dP_1(t)}{dt}+h_1P_1(t)=P_0(t)\lambda_1 \quad (5)$$

The probability that person still in the state 2 during $t+dt$ is

$$\frac{dP_2(t)}{dt}+h_2P_2(t)=P_0(t)\lambda_2 \quad (6)$$

The probability that person still in the state 3 during $t+dt$ is

$$\frac{dP_3(t)}{dt}+h_3P_3(t)=P_0(t)\lambda_3 \quad (7)$$

The probability that person still in the state 4 during $t+dt$ is

$$\frac{dP_4(t)}{dt}+h_4P_4(t)=P_0(t)\lambda_4 \quad (8)$$

The probability that person still in the state 5 during $t+dt$ is

$$\frac{dP_5(t)}{dt}+h_5P_5(t)=P_0(t)\lambda_5 \quad (9)$$

The probability that person still in the state 6 during $t+dt$ is

$$\frac{dP_6(t)}{dt}+h_6P_6(t)=P_0(t)\lambda_6 \quad (10)$$

The probability that person still in the state 7 during $t+dt$ is

$$\frac{dP_7(t)}{dt}+h_7P_7(t)=P_0(t)\lambda_7 \quad (11)$$

The probability that person still in the state 8 during $t+dt$ is

$$\frac{dP_8(t)}{dt}+h_8P_8(t)=P_0(t)\lambda_8 \quad (12)$$

The probability that person still in the state 9 during $t+dt$ is

$$\frac{dP_9(t)}{dt} + h_9 P_9(t) = P_0(t)\lambda_9 \tag{13}$$

The probability that person still in the state 10 during $t+dt$ is

$$\frac{dP_{10}(t)}{dt} + h_{10} P_{10}(t) = P_0(t)\lambda_{10} \tag{14}$$

In conclusion, the human performance reliability is

$$P = P_0 + P_1 + P_2 + P_3 + P_4 + P_5 \tag{15}$$

4. Establishes a new human system reliability model of the whole green construction engineering

As a result of the human system in green construction engineering has its complexity, the relationship between elements in this system can't be expressed by simple series connection, parallel connection or on-off connection, so this paper analyzes the reliability of the human system in green construction engineering based on integrated network analysis and ant colony algorithm. Firstly, the human system in the green construction engineering is divided into n parts. Secondly, the human reliability and weights in every part are calculated. Finally, the reliability of the whole system in green construction engineering can be obtained.

4.1 Reliability analysis of human systems in the construction division engineering

As an example, let us look at the human system in one construction part, the analysis of other part of construction has used the same method. Firstly, this paper analyses the factors affecting human performance reliability in construction part and establishes a mixed network composed of n nodes and arcs.

(1) Establishes the new model. Assuming: 1) each human system in construction parts is independent. 2) Each arc has only two kinds of state that are reliable state and failure state and each arc's failure is independent. Then, establishes the connection matrix C and numbers the nodes in the network that are called $1, 2, \cdots n$.

$$C = \left[c_{ij}\right]_{n\times n} \text{ (i=1, 2,} \cdots \text{n; j=1, 2,} \cdots n), \tag{16}$$

(2) Calculates the minimal path set. The minimal path set is defined as the set of arcs that if gets rid of one of the arcs, it can't work normally. In calculating of minimal path, sets in a network system, three methods that are called connection matrix, determinant method and node traversal method are more mature than other methods [4]. But the three kinds of methods have large operation in a complex network, the paper uses an ant colony algorithm to search the minimal path set.

Supposes there are n nodes and m ants. The probability of ant K moving from i node to j node at the time of t can be calculated by

$$p_{ij}^{k}(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha}[\eta_{ik}(t)]^{\beta}}{\sum_{s\subset J_k(i)}[\tau_{is}(t)]^{\alpha}[\eta_{is}(t)]^{\beta}} & j \subset J_k(i) \\ 0 & others \end{cases} \tag{17}$$

Where, $p_{ij}^{k}(t)$—the probability of ant K moving from i node to j node at the time of t

$\tau_{ij}(t)$—The strength of pheromones left by ants between i node and j node at the time t and the ant K determines how to go the next step according to the pheromones in the moving process

$J_k(i)$—The set of nodes that allows ant K to arrive at the next step

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{18}$$

Where, η_{ij}—the heuristic factor

α—The pheromones that shows the relative importance of the trajectory

β—The expected heuristic factor that indicates the importance of visibility

$d_{ij}(i, j = 1, 2, \cdots n)$—Routing group that ants transfer from i node to j node

When an ant K moves from the start node S to the end node T and then moves back to the start node S, the route S-T is one of the minimal path sets of the network, updates the pheromones on the path after one ant gets over.

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij} \tag{19}$$

$$\Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \tag{20}$$

Where, ρ—the volatile coefficient of pheromone

$\Delta\tau_{ij}$—The recruitment of pheromones after iteration

$\Delta\tau_{ij}^{k}$—The amount of pheromones after ant k get over the cycle path

The detailed steps of the algorithm are

1) The initialization of parameters. Makes t=0, N=0, then sets up the maximum of the cycle number

N. $\Delta\tau_{ij} = const$, $\Delta\ \tau_{ij} = 0$ (21)

2) N=N+1.

3) K=k+1. K—the amount of ants.

4) The ant selects the next nodes and don't stop until reaching the end nodes T, then returns to the start node S according to the formula 4.1.

5) Compares k with m. If k<m, returns to the third step, otherwise returns to the sixth step.

6) Updates the pheromones on the path according to the formula 4.2 and 4.3.

7) If it meets the end conditions ($k \geq m$), then ends the loop and outputs the result. Otherwise, eliminates the information and return to the second step.

The results of the above algorithms can be got by MATLAB and then we can obtain the minimal path sets of the network.

$A_i(i = 1, 2, \cdots x)$—The minimal path sets

If one of the minimal path sets is reliable, the network system is reliable. In other word, all of the minimal path sets in the network is a parallel system. The reliability value of one of the minimal path sets is equal to the result of the value of the reliability of arcs which belonging to the minimal path set multiplying together.

$R = P\left\{\bigcap_{i=1}^{x} A_i\right\}$, R—the reliability of the human system in a construction part.

Gets all parts of construction in the green construction, according to the above method, and then obtain weights of all parts of construction according to the AHP (Analytic Hierarchy Process).

$$R_s = w_1 R_1 \times w_2 R_2 \times \cdots \times w_n R_n \tag{22}$$

Where, R_s—the human performance reliability of the green construction

w_i—The weight of parts of construction $(i = 1, 2, \cdots, n)$.

4.2 Calculating weights of factors affecting the human performance reliability of the green construction

In the human system of the entire green construction, the five factors have different influence on the reliability of the human system. This paper uses ANP to obtain weights of different affecting factors. These five factors affecting the reliability are divided into the physiological factor, the psychological factor, personal skills, working environment and green construction management in the paper.

Analytic network process (ANP) was proposed in 1996 by T. L. Saaty who is a professor in the University of Pittsburgh in American, which is developed based on the analytic hierarchy process [15]. ANP is a method that considers the interaction between factors and the adjacent level and uses the

super matrix to make a comprehensive analysis and get the mixture weights of factors which affect each other.

The weight vector of factors affecting the reliability of the construction part.

The new established model in this paper is a super matrix model, and this paper analyzes the weights of factors as a criterion of reliability. The steps are shown as follows:

Establishes a super matrix. Firstly, looks the reliability as the criterion and looks the one factor of affecting reliability as the secondary criterion; then, compares this factor with other factors and gets the relative importance degree. In the other word, gets the value of other factor 'influence degree on this factor in the system. Looks five factors affecting the human performance reliability as five unite to calculate each eigenvector. Finally, looks every factor as the secondary criterion in turn to establish the judgment matrix, and establishes super matrix W.

$$W = \left[W_{ij} \right]_{5\times5} (i = 1, 2, \cdots, 5; j = 1, 2, \cdots, 5) \tag{23}$$

Where, W_{ij} —The vector matrix that can eOxpress the influence degree of the j factor on the i factor, whose column vectors in the matrix is eigenvectors that are got by judgment matrix in step one.

Establishes the weight matrix. Establishing the judgment matrix is based on data on the influential degree obtained by all factors affecting the reliability that are making a comparison with one factor affecting the reliability which is used as a secondary criterion in this model. Then, can set up five judgment matrix by using five factors influenced reliability as a secondary criterion respectively. Finally, calculates eigenvectors of the five judgment matrix and establish the following weight matrix.

$$a = \left[a_{ij} \right]_{5\times5} (i = 1, 2, \cdots, 5; j = 1, 2, \cdots, 5) \tag{24}$$

Establishes the weighted super matrix and calculates the result. The super matrix is composed of several matrixes that are established based on the influence degree of one factor that is affected by the other factor; therefore the sum of all column vectors is not equal to one. So it cannot be calculated by the power multiplication method. This paper uses the weighted super matrix to calculate the super matrix. Elements of the column vector in the weighted super matrix represent the influence degree of the other factor on a factor. If those have no effect on it, the element is 0. The formula of the weighted super matrix is shown as follows:

$$W_{+} = \left[a_{ij} W_{ij} \right]_{5\times5} (i = 1, 2, \cdots 5; j = 1, 2, \cdots 5) \tag{25}$$

Using the multiplication power method to calculate the weighted super matrix and get weight vectors of five factors affecting the reliability.

The weight vector of factors affecting the reliability of green construction. Gets weight vectors of the five factors of all parts of construction according to the method mentioned in section 4.2.1. Calculates the weight of each construction part by using the weight of construction parts to multiply by the weight vector of one factor and add them together. Then, this section can get the weight of one factor affecting the human performance reliability of green construction. In the same way, we can get the weight of the five factors in green construction.

Through calculating the weight of the five factors in green construction, we can know the influence degree of working environment and green construction management on the human performance reliability of green construction. We can also get the key factors thought the weight of five factors, which will help to improve the human performance reliability of green construction. The paper uses the method of ANP, which considers the mutual effect between five factors, which makes the model closer to the actual condition.

5. Conclusion

The construction phase is a key phase to ensure the quality of green construction. Most of unsafe accidents occurred in the construction phase that is caused by human. The paper analyzes the factors affecting the human performance reliability and establishes the individual reliability model which can

calculate the individual reliability. Then, a new human system reliability model of the whole green construction engineering based on integrated network analysis and ant colony algorithm is set up. Finally, this paper applies the new model to analyze weights of factors affecting human performance reliability in green construction, which can help us to find key factors and improve the human performance reliability. The paper draws the following conclusions and wishes to provide some references to the research on the human performance reliability of green construction engineering in the future.

The factors affecting human performance reliability of green construction engineering can generally be divided into the objective factors and the subjective factors. The paper divides them into five factors on the basis of the objective factors and the subjective factors, which consist of physiological factors, psychological factors, personal skills, working environment and the green construction management factor. On establishing the individual reliability, this paper firstly considers green construction management as one factor. In this paper, we can also analyze the influence degree of the working environment and green construction management on the human performance reliability. This paper also establishes the individual model and gives a method to calculate the individual reliability.

In order to improve the human performance reliability of the green construction, the paper uses ANP to get weights of five factors and gets the key factors and other factors, which can help to formulate corresponding measures according to the key factors and other factors to improve human performance reliability of the green construction.

By using ANP to analyze in the third chapter, we can get weights of working environment and green construction management for the human performance reliability. So we can obtain the influence degree of the working environment and the green construction management on human performance reliability of green construction, which can provide a reference for future researches.

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