How does the flow of construction workers affect safety culture?

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Abstract: Active and mature safety culture can effectively reduce the occurrence of safety accidents. However, in international projects, construction workers from different countries gather in one project, which will inevitably lead to the integration of safety culture. A bad safety culture can have a negative impact on the overall safety culture. This paper constructed a construction safety culture fusion model, and then used computer simulation technology to simulate the model. By adjusting the parameter values, the influence of the flow of construction workers on the safety culture was analyzed. It was found that the mobility of construction workers will not change the critical value of a cultural outbreak, but it will change the accumulation period before the outbreak; strengthening the cultivation of safety culture identification of construction workers can effectively prevent the impact of the poor safety culture; the new influx of safety culture first affects leaders in the project.

1. Introduction
At present, with the continuous promotion of the policy of "One Belt And One Road" of China, China’s construction enterprises have stepped up the pace of going out. As an important part of human resource management of overseas construction projects, hiring local staff is an effective way to reduce human cost and management risks. The extension project of Bata port of Guinea, a city on the equator, has a total number of 700 people, including 268 local employees. The comprehensive proportion of local staff is about 40% of the total number of the berthing construction project of Mauritania [1]. At the peak of the construction, there were about 300 local workers in the project of the sach oil field in Ecuador, up to 70% of the total number. Even some countries have explicitly stipulated the minimum proportion of local staff to be employed by the project, such as Angola stipulates that foreign-funded enterprises must recruit more than 30% of the angolans [2].

China’s overseas projects mostly concentrated in the less developed areas. Due to the local employees are limited to accept education, their technical level is generally low and safety awareness is not strong. So they often have unsafe behaviours, carry a poor safety culture. Because of the different language and communication barriers, the poor safety culture carried by these workers into the construction site will conflict with the Chinese safety culture, which affects the workplace safety and increases safety accidents.

At present, research on the impact of unsafe cultural communication on safety culture at the construction site is still in its infancy. But in the field of cultural communication, many scholars have achieved fruitful research achievements[3-5]. The early culture dissemination research is based on the theory of sociology or the qualitative analysis and quantitative study[6-10]. In recent years, using the complex network theory can make the detailed description of the relationship between every subjects of
a network and its dynamic changes, which received the attention from the studies of multiple research fields. Some scholars also applied complex network theory in the research field of cultural transmission, such as X H Xiao et al.[11], who built a complex network of cultural communication. Transmission media have been divided into several clusters, then they studied the culture in the cluster and across the cluster. After analyzed the culture propagation path of large project, H Wei et al.[12] simulated cultural transmission under the three layers of the spread of transit-stub network topology, obtaining reproduction of cultural transmission in the large construction project. According to the existing research results, the cultural transmission research, based on the complex network and the computer simulation technology, broadens the various assumptions of cultural transmission and builds a cultural transmission model which is closer to reality.

The spread and formation of the safety culture is the process of the co-evolution of the individual and interpersonal network [13]. With the aid of complex network, this study analyzed safety culture communication network topology and constructed the cultural transmission model. Then, we used the computer simulation technology to explore the rule of poor safety culture dissemination and researched the impact of employee mobility on safety culture.

2. Network Topology of Poor Safety Culture Transmission

The negative safety culture is transmitted through the interaction of employees' work and life at the project site, and each employee can be the communicator or receiver of the unsafety culture. To simplify the individual to the node, the influence relationship is abstract as the connection between the two nodes, and the network structure diagram was shown in figure 1. The degree of nodes \( v_i \) in the network is defined as the number of nodes that can be directly affected by the subject \( v_i \) in the cultural communication network.

![Figure 1. Network composition diagram](image)

At present, there is little literature to study the network topology of the safety culture communication in the project site, but we can analyze the distribution characteristics of the node degree in the network. According to the research achievements of project organization and management, in the project organization, the decision maker is at the highest level of the entire organizational framework. It directly affects managers and workers of the project through the development of safety rules and regulations and personal charisma[14]. The manager, through the implementation of safety regulations and other measures, has a direct impact on the employees, and the connection degree is much smaller than that of the decision maker. In the project organization, a large number of construction workers only have a direct impact on the working life and the people who are in communication, and the connectivity is much smaller than that of the decision makers and managers. That is to say, in the safety culture communication network, a small number of nodes have a very large degree of connectivity, while most of the nodes have only a small degree of connection. Degree distribution properties of network is the typical power law. Therefore, we believe that the network of negative safety cultural transmission has a typical power law distribution feature, which can be considered as a scale-free network.

3. Poor Safety Culture Transmission Model

Through the above analysis, we construct a model of poor safety culture propagation on the basis of unmarked complex network. In general, when the local construction personnel with poor safety culture flows into the site of the project, the poor safety culture will reflect poor safety behavior in the work and life. The safety culture will gradually be affected and fall into cultural conflict.
3.1 Model hypothesis
Through the above analysis, we make the following assumptions before constructing the model of the cultural transmission of unhealthy safety culture:

(1) The implementation of overseas projects is easily influenced by the local culture, and the proportion of local employees is large. Therefore, we assume that when a new bad safety culture flows into the construction site as a strong safety culture, all employees will be affected by it, resulting in a poor safety culture throughout the work site.

(2) There are only two types of main safety culture in the project: the infection state with the poor safety culture called I, and the healthy state of the safety culture called H.

(3) Without considering the influence of safety training and other factors, infected people carrying a bad safety culture have an impact on healthy individuals, resulting in the occurrence of healthy individuals being completely infected. Once an individual is infected, he cannot recover.

3.2 Building the model
Based on the above assumptions, the process of transmission of poor safety culture is simplified as shown in figure 2, and the following description is made:

\[ \sum_{i=1}^{n} D_i(i=1,2,3,...) \]

Figure 2. Schematic of the transmission of poor safety culture

(1) Infected individuals affect healthy neighbors in the network. The infectivity is defined as G, which means the ability of adverse effects of safety culture is only related to the individual characteristics of the infected individual, regardless of the degree of individual connectivity.

(2) Healthy individuals are constantly infected by infected individuals in the network. \( H_i \) represents the state of health after i times' infection. The impact of each infection will result in a certain degree of variation to the healthy individuals, and the number of variation after the i times' infection is \( D_i = \mu G / I(i=1,2,3,...) \). Among them, \( \mu \) is proportional coefficient, \( R \) represents the immunity of healthy individuals to the bad safety culture. The higher the identity of healthy individuals to their own safety culture, the greater the immunity to bad safety culture. The amount of variation \( D_i \) is proportional to infectivity \( G \), and inversely proportional to immunity \( R \).

(3) After the state of health culture was affected by the poor safety culture, we called the critical value \( C \). In the healthy state, after the n times' infection, the cumulative variation of the infection was \( D = \sum_{i=1}^{n} D_i(i=1,2,3,...) \). When \( D>C \), it is believed that the health safety culture is changed to infestor with unhealthy culture. The critical value of individual mutations is positively correlated with their own safety values, safety awareness and safety habits.

Due to the construction workers on the project exists differences in job, age, professional skills, literacy and other areas, so the individual cultural infectivity \( G \) of construction workers, immunity \( R \) to poor safety culture and the critical value of variation \( C \) are different. Take cultural infectivity as an example, a few individuals acting as leaders of the organizations have an impact on others on the construction site. Also, there are individuals who rarely have an impact on others. Most people's ability to influence others is in an intermediate state, conforming to normally distributed trait. So it can be assumed that individual cultural infectivity \( G \) is conform to the normal distribution \( G \sim N(\mu, \delta^2) \). Similarly, it is assumed that immunity \( R \) and the critical value of variation \( C \) conform to the normal distribution.
4. Model Simulation

This section made a computer simulation of poor safety culture propagation models with MATLAB software, and studied propagation law of bad safety culture on scale-free networks. We used the construction algorithms of scale-free network model given by Barabasi and Albert[15]:

(1) Growth: in the network, its initial number of nodes is \( m_0 \), then introduce a node to the network again and again, connect the node to the nodes in the network, \( m < m_0 \).

(2) Preferential attachment: the connected probability of a newly joining node is \( V_i \), a node already existing on your network is \( \Pi_i \). The relationship between \( V_i \) and \( \Pi_i \) is: 
\[
\Pi_i = \frac{k_i}{\sum_j k_j}.
\]

Using this algorithm to build a network, after \( t \) steps, we can get a complex network with \( N=t+m_0 \) nodes and \( mt \) sides. According to the rate equations[16], we calculated the distribution of networks degree, which is a power-law distributions in nature.

(3) Build parameter: \( m=m_0=10 \) means each new inflow of workers has a direct impact with 5 employees on the project site. The entire network of nodes degree distribution function is:
\[
P(k) = \frac{2m(m+1)}{k(k+1)(k+2)} = \frac{220}{k(k+1)(k+2)}.
\]

Through investigating the number of personal of construction sites, we set the evolutionary steps as \( t=2990 \), which gives us a bad safety culture network with total nodes \( X=3000 \).

(4) Set the initial parameters: number of initial infections \( x_0=15 \), infectivity \( G \) is conform to the normal distribution \( G \sim N(5.1) \), immunity \( R \) is conform to the normal distribution \( R \sim N(30.1) \), critical value of variation \( C \) is conform to the normal distribution \( C \sim N(50.1) \), Set \( \mu=1 \). \( G \), \( R \) and \( C \) cannot be negative. So when \( G<0 \), \( R<0 \), \( C<0 \), their value are taken as 0.

(5) Besides settings: when all individuals on the network configuration are infected or simulation number is greater than or equal to 1000, simulation ended.

4.1 The effect of the initial number of infections on the spread of poor safety culture

By adjusting the parameter values \( x_0 \) of the initial infection number, we analyzed the impact of different personnel mobility on the construction safety culture. Respectively set \( x_0=10,15,20 \), the simulation results were shown in figure 3.

As seen from figure 3, with the increase of the number of initial infection, it took less time for poor safety culture in network to infected all individuals. When \( t<200 \), there was no change in the number of infected people in the network. It indicates that, at this time, healthy individuals have certain immunity to the invasion of poor safety culture, that is, healthy individuals do not reach the critical value of individual mutation status, thus preventing construction workers from contracting a bad safety culture. When \( t>200 \), individuals began to be constantly infected successfully in the network. When \( t=400 \), the total infected individuals in the network have been largely increasing until all individuals were infected by the bad safety culture.

Although the number of different initial infections lead to differences in the time of poor safety culture in the network, the curves for the three initial infections had an inflection point for significant outbreaks. When the number of infected people in the network reached this point, it began to show a rapid spread. From figure 4, there was a delay in the occurrence of inflection points under the three initial infection numbers. However, the vertical axis of the image corresponding to the inflection point, that is, the number of infectious states in the network, was consistent, and was distributed between 200 and 300. In order to analyze this phenomenon, we used software to show the number of individuals infected in each time step under different initial infection numbers, as shown in figure 4.
Figure 3. Construction mobility affects project site safety culture

From figure 4, we can see that before $t=200$, very few individuals have been infected of three initial infections. When the number of initial infections $x_0=10$, the nodes in the network began to have the sign of being infected just till $t=400$. Although the initial number of infections was different, the shapes of the three curves were very similar. When a certain point in time was reached, the workers in the network began to accelerate to be infected, which showed the characteristics of the outbreak, and then began to fall rapidly after the peak until all the individuals in the network were infected. In the network, the phenomenon that nodes were accelerated to infect caused the curve to change to a typical s-type nature, as shown in figure 4.

We believe that in the process of poor safety culture dissemination, there exists a critical value of poor safety culture infection outbreak. When the number of infected is less than this critical value, the transmission of bad safety culture is very slow, and it is at the stage of infection accumulation. However, when the number of bad safety culture carriers exceeds the critical value, it reaches a turning point in the dissemination of poor safety culture, and the bad safety culture will show the characteristics of explosion propagation. Therefore, in the work of constructing safety culture, it is necessary to fully identify the type of safety culture, control the construction personnel carrying the bad safety culture into the construction project, and limit the number of carriers of poor safety culture up to the critical value of the outbreak.

4.2 The influence of safety culture identification on the safety culture of the project site

By adjusting the parameter value of immunity $R$ of the safety culture, we can analyze the influence of the construction workers’ flow with safety culture identification on the safety culture of the project. By adjusting the individual's parameter values of safety culture recognition, this paper analyzed the impact of construction workers' mobility on safety culture integration under different safety cultures. Generally speaking, the more the construction workers agree with their own safety culture, they will insist on accepting the original safety culture and it is difficult to be influenced by other types of safety culture. In order to verify the speculation, we modified the individual's safety culture identity based on the initial calculation parameters, respectively set $R \sim N(30,1)$, $R \sim N(25,1)$, $R \sim N(15,1)$ to carry on the simulation, and took the average of the results after multiple simulation, as shown in figure 5.

It can be seen from the figure 5, with the reduction of the immunity of individuals in the network to the bad safety culture, the time taken by the bad safety culture to spread throughout the network was significantly shortened. In addition, it can be seen that as the individual’s immunity to the bad safety culture was reduced, the critical value of the infectious state showing an outbreak of growth in the network has not changed, which was still between 200 and 300. It shows that the safety culture identification of the construction workers in the network has nothing to do with the critical value of the outbreak growth, and the safety culture recognition of the construction workers could only prolong the
time when the bad safety culture spreads to the whole network. From this, it can be determined that for a specific safety culture network, the critical value of the number of infected states is 6.6% to 10% of the total number of nodes in the network.

As the individual immunity in the network decreased, the curve in figure 5 not only reached the critical value of the outbreak propagation earlier, but also became steeper, which meant that the bad safety culture in the network spread faster. To explain this phenomenon, we also have the number of infected individuals within each time step of different immunity, as shown in figure 6.

![Figure 5](image1.png)

**Figure 5. The influence of safety culture identification on the safety culture of the project site**

It can be seen from figure 6 that the trend of the three curves was basically the same, and there was an accumulation time of the number of infection states in the early stage; then it grew rapidly, and after reaching the peak of growth, it dropped rapidly until all the individuals in the network were infected. However, as the individual's immunity declined, the shape of the curve showed a big difference. Compared with $R \sim N(30,1)$, the $R \sim N(25,1)$ had an accumulation of infectious state earlier, and after reaching the critical value, the curve trend was steeper and the peak value of the curve was higher. It showed that when the unsafe culture immunity of individuals in the network was reduced, the bad safety culture was more likely to infect individuals and the infection was faster.

![Figure 6](image2.png)

**Figure 6. The number of infected individuals within each time step of different safety culture recognition**

4.3 Analysis of the ways of dissemination of poor safety culture

This section will study the propagation path of poor safety culture by analyzing the changes in the average degree of infected nodes in the network of bad safety culture. In this paper, MATLAB software was used to obtain the variation of the average degree of infected nodes with time in the case of three kinds of poor safety culture immunity distribution, namely $R \sim N(30,1)$, $R \sim N(25,1)$, $R \sim N(15,1)$.

As shown in figure 7, the average degree of the initial infection was different, due to the random initial infection in the simulation process. Because of the combination of the bad cultural immunity of the construction workers and the critical value of the individual state, no employees were infected, when the initial infected individual brought the bad safety culture carried to the construction site. So the three curves in the figure were straight lines parallel to the horizontal axis at the beginning. After that, the average degree of infected nodes represented by the three curves began to increase, which peaked after a period of time, and then began to decline. The mean value of the infected nodes in the final three curves was equal, that is, all nodes in the network have been infected. Figure 8 shows the average degree of infected nodes at each time point under different immune distributions.
Figure 7. Variation of the average degree of infected nodes under different immunity $R$ values

Figure 8. Variation of the average degree of infected nodes under different immunity distribution

As can be seen from figure 8, no nodes were infected at the initial stage. After the construction workers carrying the bad safety culture flow into the project for a period of time, the average degree began to change. Obviously, the average degree of infected nodes was very large at the beginning, and after a period of time, the decrease occurred. Then the bad safety culture propagated to the entire network and no longer propagated. The average degree of infected nodes in the network changed to zero. Nodes with a large degree of connectivity in the network would be infected first. Since a node with a large degree of node could be connected to more nodes, so when these nodes were infected as carriers of a bad safety culture, the spread of bad safety culture in the network would accelerate. Specifically, it can be understood from the construction project that when the construction personnel enter the construction project site by individuals or teams, the individuals with relatively large connection degree in the project will have a greater probability of contact with them, resulting in the spread of bad safety culture. That is to say, after the construction personnel flow into the project, the collision of safety culture should first occur in the people with relatively large connections, such as managers and decision makers.

5. Conclusions

Based on the above analysis, we propose the following four recommendations. First, construction company managers should introduce safety knowledge assessment into staff recruitment. When hiring local workers, the company should use the method of safety knowledge assessment to check the safety culture level of the candidates. Through screening, managers should control the number of bad safety culture carriers entering the construction site within 10%. Second, companies should conduct safety training and publicity regularly, enhance the local staff’s acceptance to China’s outstanding safety culture. At the same time, Chinese workers’ immunity to unsafe culture should be strengthened. Then, overseas construction companies should strengthen the safety culture training of project leaders. Because they are at the heart of the entire safety culture network. A bad safety culture will first affect them. As general contractors, China’s overseas construction companies should focus on the construction of safety culture and establish a comprehensive safety system and penetrate the safety culture into the each link of construction.

This paper took the construction workers who carried the poor safety culture into the construction site as the research object and analyzed network topology of poor safety culture’s transmission. Then, we constructed the propagation model of poor safety culture, revealed the influence mechanism of the overseas construction workers to the safety culture of the project site by computer simulation. The results show that there is an accumulation period and a critical value for the propagation of poor safety culture. In the process of collision of safety culture, the mobility of construction workers would not affect the critical value of safety culture outbreaks, and only changes the accumulation period before the outbreak. By increasing the recognition of construction workers on safety culture, it could be prevented from being
influenced by other different safety cultures. In the construction of safety culture, leaders in the project and leaders in informal organizations need safety culture training. However, the assumptions of the propagation model in this paper have some limitations, then we can further improve the propagation model, and verify the reliability of the propagation model through experiments.

References

[1] Cooke, F. L., Wang, D., Wang, J. (2017) State capitalism in construction: Staffing practices and labour relations of Chinese construction firms in Africa. J. Ind. Relat., 60: 77–100.
[2] Gomes, Vanessa, Silva, M. G. D. (2005) Exploring sustainable construction: implications from Latin America. Build. Res. Informat., 33:428-440.
[3] Ogle, Russell, A., Dee. S. J. (2014) Using assessments to improve process safety culture. Process Saf. Prog., 33:148-151.
[4] Parker, Dianne, Lawrie, M., Hudson, P. (2006) A framework for understanding the development of organisational safety culture. Saf. Sci., 44:551-562.
[5] Glendon, A. I., Litherland, D. K., (2001) Safety climate factors, group differences and safety behaviour in road construction. Saf. Sci., 39:157-188.
[6] Filip, Florin, G. (1996) Information Technology Culture Dissemination In Romania, Knowledge, Technology Transfer and Foresight. Springer, Netherlands.
[7] Azinian, Herminia. (2001) Dissemination of information and communications technology and change in school culture, Information and Communication Technologies in Education. Springer, US.
[8] Wrench, Jason, Candice Thomas Maddox, and Pe., V. (1998) Mass communication research methods. Palgrave.
[9] Guldenmund, F. W. (2000) The nature of safety culture: A review of theory and research. Saf. Sci., 34:215-257.
[10] Choudhry, Rafiq, M., Fang, D., Mohamed, S. (2007) The nature of safety culture: A survey of the state-of-the-art. Saf. Sci., 45:993-1012.
[11] Xiao, X. H., Ye, G. W., Wang, B., He M. F. (2009) Cultural dissemination in a complex network. Physica A, 5.
[12] Wei, H., ZHOU, J., ZHU, Z. T. (2015) Study on Cultural Transmission Path in Large-scale Construction Projects Based on Network Topology. Journal of systems science, 85:79-82.
[13] Toole, O., M. (2002) The relationship between employees' perceptions of safety and organizational culture. J. Saf. Res., 33:231-232.
[14] Kines, P., Andersen, L. P. S., Spangenberg, S. (2010) Improving construction site safety through leader-based verbal safety communication. J. Saf. Res., 41:399-403.
[15] Barabasi, A. L., Albert, R. (1999) Emergence of scaling in random networks, Science.
[16] Dame, Notre. (2002) Statistical mechanics of complex networks. Review of Modern Physics, 74:xii.