ISM-Based Analysis of Influencing Factors and Countermeasures of Construction Safety

Zhui Dong, Heng-ying Li, and Hai-qing Yin

Abstract Through the systematic analysis of causing factors of the construction safety accidents, the relationship among 12 causing factors was confirmed. By using ISM theory, the hierarchical ISM model was constructed, which assort all causing factors of construction safety accidents into three hierarchies. The direct reasons are construction workers' safety awareness and safety equipment and facilities. The indirect reasons are machinery and equipment maintenance and improvement, labor intensity, inputs of security cost, and construction schedule. The root reasons are construction safety laws and regulations, and quality of managements. According to the search results, root reasons are vital influencing factors, which are in-depth and fundamental. Besides, construction safety accidents analysis proved the applicability of the ISM model.

Keywords Construction safety • Interpretative structural modeling • Influencing factors

1 Introduction

In 2011, it is reported that there were a total of 589 accidents and 738 deaths from housing municipal engineering safety production. The number of accidents was decreased by 38 and the death toll by 34 people, which respectively falls year-on-year by 6.06 % and 4.40 % [1]. The current situation of production safety is still severe. There still exist a relative large number of accidents and deaths; tremendous accidents happen now and then; major accidents have not completely contained and the number of accidents and deaths rose in certain areas.

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Take the year of 2011 as an example, several causes can attribute to housing municipal engineering production safety accidents. Among them, there are 314 falling accidents (53.31 %); 86 collapse accidents (14.60 %); 71 struck by equipment and machineries accidents (12.05 %); 49 lifting injury accidents (8.32 %); 30 electric shock accidents (5.09 %); 20 equipment damage accidents (3.40 %); 19 other accidents (3.23 %).

Of all types of accidents, 471 cases are caused by falling, collapse, struck by equipment and machineries, which accounts for 81 % of the total, and statistically the above three types of accidents has reached to 79 % in the 2010 national housing municipal engineering production safety accidents. This paper intends to analysis above accidents based on the interpretative structural modeling (ISM) to identify key factors and propose appropriate countermeasures.

2 Basic Principles and Working Procedures of ISM

The interpretative structural modeling (ISM) is developed by J.N. Warfield between the year 1971–1973 as a systematical analysis approach for the analysis of complex systems [2]. ISM has a very wide range of applications, from the energy, resources and other international issues to domestic range of issues such as regional development, traffic accidents, as well as the problems within the scope of enterprises and individuals. Almost all these areas can apply this method [3]. It can be applied at all stages of the systems engineering, especially effective unified views.

This approach adopts the principle of the incidence matrix in graph theory to analyze the overall structure of complex systems, which are then decomposed into several subsystems (elements). Through incidence matrix, the direct relations of inter-linkages and restrictions between various elements of the system can be described. Then by further calculation, the indirect relationship between the various elements will be found and thus figures could be adopted to show both direct and indirect relations. According to such an approach, the fundamental influencing elements of the system would be found out. For the working procedure of ISM, please refer to the references [4].

3 ISM Model of Construction Safety Influencing Factors

3.1 Analysis of Influencing Factors and Their Interactions

Through access to a large number of relevant literatures, 12 factors that may affect construction safety could be initially identified. They are as follows: construction safety laws and regulations (S1), managements' safety awareness (S2), construction workers' safety awareness (S3), machinery and equipment maintenance and

Table 1 System factors' direct relation

Elements serial number (i)	Influencing factors (Si)	Elements serial number (i)	Influencing factors (Si)
0	1–12	7	6
1	No	8	No
2	1,6	9	1,8,10,12
3	1,2,7,8	10	No
4	1,2,6,7,11,12	11	1,4,6,8,9,10,12
5	1,2,4,6,7,9,11,12	12	8,10,11
6	No		

improvement (S4), safety equipment and facilities (S5), quality of managements (S6), quality of construction workers (S7), complexity of the project (S8), labor intensity (S9), work environment (S10), inputs of security cost (S11), construction schedule (S12). Their own strength and the extent of inter-action of these factors determine the construction safety accident rate (S0). These 12 factors, through a questionnaire, are distributed to relevant experts to evaluate the interaction between these elements. Then after summarizing the evaluation results and considering the views of all parties, the relationship between the above factors is obtained. Table 1 presents the interaction between these factors.

3.2 Establishment of the Adjacency Matrix

Based on the above relation tables, the adjacency matrix can be listed. Adjacency matrix is the square matrix which expresses the basic binary relations between elements of the system or direct relations. Figure 1 shows the adjacency matrix.

3.3 Establishment of the Reachable Matrix

According to adjacency matrix, the reachable matrix M. is calculated by the Matlab software. Figure 2 shows the reachable matrix M.

3.4 Dividing Elements by Hierarchy and Establishing ISM

Reachable matrix elements can be divided into reachable set R (Si) and first set of A (Si). Reachable set is a collection of elements of the system that Si can reach in reach-able matrix. Antecedent set is a collection of elements of the system that can

Fig. 1 The adjacency matrix

$$\begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\
1 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \\
1 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\
1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\
1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1
\end{pmatrix}$$

Fig. 2 The reachable matrix M

$$M=\begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\
1 & 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\
1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \\
1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1
\end{pmatrix}$$

reach Si in the reachable matrix. By calculating the R (Si) ∩ A (Si) = R (Si), the most superior unit is gained, then remove them temporarily. Similarly, the sub-unit could be calculated. By successively dividing the elements, the elements are at last divided into multi-rank hierarchical structure. Through calculation, the sys-tem is

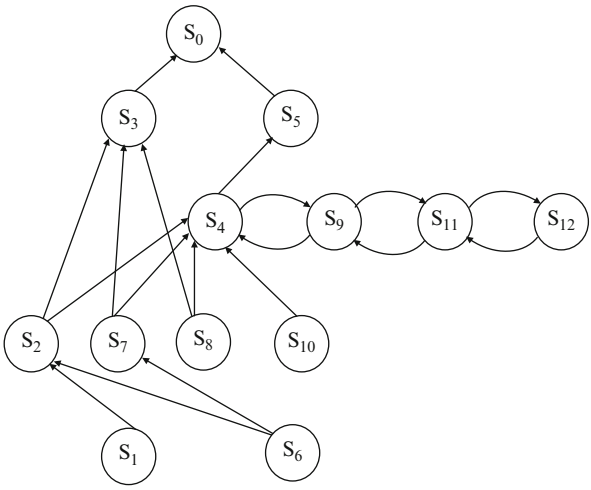

Fig. 3 The analytic structure of the construction safety influencing factors

divided into five layers as follows: I: 0; II: 3,5; III: 4,9,11,12; IV: 2,7,8,10; V: 1,6. Original reachable matrix is then divided by hierarchy. Figure 3 shows the analytic structure.

4 Conclusion

Based on the above analysis, it can be concluded as following:

The direct influencing factors of construction safety accidents are construction workers' safety awareness (S3), safety equipment and facilities (S5). To reduce construction safety accidents, the security awareness of construction workers should be enhanced first. At present, the majority of the construction workers in China are migrant workers, and a lot of them are temporary workers [5]. Their sense of security is very weak, and self-defense capability is poor. So many construction workers lack knowledge and skills of in construction safety operations, and treat the safety training prior to the approaching work as a form. Therefore, we should focus on reinforcing the safety education training of construction personnel, enhancing their safety awareness and improving their safety skills. Only by the systematic training of construction personnel, can effectively improving the safety of construction workers' operation skills and self-protection awareness be achieved.

Construction enterprises' security education and training can fall into three stages [6]. The first stage is to see the exhibition and video so that every personnel could acquire a general concept before entering the construction site, such as knowing the division and setting of the site functional areas, the location of the clinic, emergency gathering place, and emergency treatment after a security incident. The second stage can carry out relevant safety training to construction personnel, mainly allow them to clear the project safety requirements, handling method after a security incident, the

pre-arranged planning of an emergency event, and safety requirements of machinery and equipment and personal safety protective equipment. The third stage of security education and training is safety technical clarification. For each assignment and establish workers' education ledger. Construction workers must be experience a period of safety and operating skills training, and tested to obtain the certificate before the construction work. Construction workers who do not follow the operation specifications, rules and regulations should be educated, if they refuse to mend one's ways after repeated education, they may be dismissed.

Construction enterprises should also continue to increase investment in safety equipment, personal safety protective equipment, security facilities and facilities maintenance funds to ensure the effective operation of safety equipment and facilities. Then effective security measures should combined with the specific circumstances of construction. Besides, adequate security of critical security facilities is also needed in construction projects.

The fundamental influencing factors of construction safety accident are construction safety laws and regulations (S1), quality of managements (S6). To reduce the accident rate, the development and implementation of construction safety laws and regulations must be strengthened. For example, American's Common Law, Workmen's Compensation Law and Occupational Safety & Health Administration have made stipulations to determine the responsibility of the construction site safety. The safety management of the project and the economic interests of the contractor are closely linked by forcibly buying Worker's Compensation insurance and the premium rate regulation [7]. Germany has strictly implemented Labor Protection law. At the same time, the Industry Association has played a very important role in many aspects such as work-related injury insurance and research education, accreditation of security professionals, prevention and treatment of occupational diseases, and security incident handling [8]. Japan has carried out Industrial Accident Prevention Organization Law and Industrial Safety and Health Law to effectively prevent architectural production accidents [9]. Morning meeting system is implemented in the project department of all construction enterprises [10]. At the same time to raise the cultural level of the management staff, thus contributing to the improvement of the quality. Through communication and study, the management level of management is improved and the occurrence of security incidents is reduced.

Machinery and equipment maintenance and improvement (S4), labor intensity (S9), inputs of security cost (S11), construction schedule (S12). The factors mentioned above have a strong mutual influence between each other. Thus it should also be given sufficient attention in safety management of construction projects.

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