DOI:10.13434/j.cnki.1007-4546.2016.0201

Research on Safety Risk Assessment Method for Large Scale Field Operation Project

JIANG Wei-yang, ZHAO Man-yun, ZHANG Lian, SONG Wei-dong
Xi'an Institute of High Technology and Science, Xi'an 710025, P. R. China

Abstract: By applying man-machine-environment system engineering theory, safety risks on large scale field operation project have been evaluated in this article. The factors concerning with the man, machine and environment in system were proposed separately. The value for lowest indexs was determined by decision-making of expert group. The weights were calculated based on AHP, and then safety risk assessment in different layers was made. The results show that the assessment method is reasonable, and it is significant for large scale field operation project safety managerment.

Keywords: large scale field operation project; safety risk assessment; man-machine-environment system

1 Introduction

Large scale field operation project is of long-term construction, great operation difficulties and complex built environment, which is in a high security risk[1-4]. The previous studies on large scale field operation project mainly focus on the object, personnel and management separately. From the point of view of process management, the construction of management and control system of operating risk have been structured in the reference[5]. In the reference[6], a method based on Bayesian network is put forword to quantitatively evaluate the site risk of drilling operation and to find out the source of the risk, in two aspects: "people's unsafe behavior" and "the unsafe state of the thing". A large number of security indicated that personnel, machine, environment are the major causes of risk in field operations. It's hard to agree that there is an dimension could be ignored in an field operation safety. In practice, security risk assessment model based on the theory of man-machine-environment system has been widely applied in space, air traffic control and other areas of safety management[7-11].

Combining the characteristics of large scale field operations project, an assessment index system based on man-machine-environment system and AHP is structured in this paper, to explore a quantitative analysis method on security risk assessment in large scale field operations project.

2 Evaluation index system

According to the characteristics of the overall risk on the man-machine-environment system, combining with relevant studies and security risk analysis, the safety risk assessment index system for large scale field work project is structured from dimensions of man, machine and environment, as shown in Table 1.

Received 02 June 2016
This work was supported by the National Natural Science Foundation of China (71172124, 71201124); Projects of the National Social Science Foundation of China (15GJ003-245); Science Foundation for The Youth Scholars of Xi'an Institute of High Technology and Science (2015QNJJ011).

Table 1 Evaluation index system and coding

Target layer	Criterion layer	Index layer	Secondary index or index description
Overall risk of man-machine-environment system(A)	Man (B_1)	Project experience (c_{11})	Undertake or participate in similar projects
		The qualification certification Obtaining(c_{12})	Qualified on the assessment of position required ability
		Technical quality(c_{13})	Years of operating equipment
		Psychological quality(c_{14})	Psychological coping of individuals under stress
		Safety Awareness(c_{15})	Awareness of safety risk
	Machine (B_2)	The safety of equipment design(c_{21})	Design performance according to the security specification
		Simplicity of operation(c_{22})	Equipment operation is simple and safe
		The reliability of technical condition(c_{22})	Equipment failure rate in the past
	Environment (B_3)	Natural environment(c_{31})	Terrain and surface features(d_{311})
			Meteorology and hydrology(d_{312})
			Season(d_{313})
		Social environment(c_{32})	Legal environment(d_{321})
			Folk environment(d_{322})
			Cultural environment(d_{323})
		Management environment(c_{33})	The efficiency of safety education(d_{331})
			The completeness of regulation(d_{332})
			Safety inspection and rectify the problem(d_{333})
			Emergency plan(d_{334})

3 Safety risk assesment model

3.1 Scoring of indicators

The risk level was divided into 5 grades, which were: Negligible risk, Acceptable risk, Obvious risk, Significant risk, Serious risk. The comment set is:

V = {Negligible risk, Acceptable risk, Obvious risk, Significant risk, Serious risk} = {1,2,3,4,5}

There are q indexes beloged to criteria p. These indexes would be evaluated by m experts, the score matrix of all the subordinate indexes are constructed as:

$$K = (k_{uv})_{m\times q} \qquad u,v,m,q = 1,2,\cdots,n \tag{1}$$

Among them, the score of index t is

$$K_t = \begin{bmatrix} k_{1t} \\ k_{2t} \\ \vdots \\ k_{mt} \end{bmatrix} \qquad t,m = 1,2,\cdots,n \tag{2}$$

3.2 Index score fusion using expert weights

Because of the experts' own different situation, such as professional accomplishment, knowledge structure, experience and understanding of the task's unique situation, it is necessary to assessment of the characteristics of the experts to carry out their each adopted weight. The adopted weight of expert were dependented on those 4 factors: "Title" as F_1, "Working years" as F_2, "Familiar degree of the safety risk of field operation" as F_3, "Familiar degree of the task" as F_4. Score of 4 factors and the standard relative weight value (SRWV) were shown in Table 2.

Table 2 Factors affecting the weight of experts and evaluation rules

F_1	Score	SRWV	F_2	Score	SRWV	F_3	Score	SRWV	F_4	Score	SRWV
Senior engineer	5	0.45	>10	5	0.42	Very familiar	5	0.36	Very familiar	5	0.45
Engineer	3	0.27	5~10	4	0.33	Familiar	4	0.29	Familiar	3	0.27
Assistant engineer	2	0.18	3~5	2	0.17	Alittle familiar	3	0.21	A little familiar	2	0.18
Operator	1	0.09	<3	1	0.08	Not familiar	2	0.14	Not familiar	1	0.09

w_{ij}^e is the weight of expert i adopted in factor j. In this evaluation task, the comprehensive weight of expert i is:

$$w_i^e = \frac{\sum_{j=1}^{l} w_{ij}^e}{\sum_{i=1}^{m}\sum_{j=1}^{l} w_{ij}^e} \qquad i, j, l, m = 1, 2, \cdots, n \tag{3}$$

All experts' adopted weight vector in this evaluation is

$$\boldsymbol{W}^e = [w_1^e, \quad w_2^e, \quad \cdots \quad w_i^e, \quad \cdots \quad w_m^e]^{\mathrm{T}} \qquad i, m = 1, 2, \cdots, n; \ 1 \leqslant i \leqslant m \tag{4}$$

Combinating all experts' score with their adopted wight, the final score of index t is

$$k_{pt} = (\boldsymbol{W}^e)^{\mathrm{T}} \times K_t \qquad p, t = 1, 2, \cdots, n \tag{5}$$

The final score vector of all indexes belonged to criteria p is

$$\boldsymbol{K}_p = [k_{p1}, \quad k_{p2}, \quad \cdots \quad k_{pt}, \quad \cdots \quad k_{pq}] \qquad t, p, q = 1, 2, \cdots, n; \ 1 \leqslant t \leqslant q \tag{6}$$

3.3 Determining the index weight by AHP method

1) Structuring judgment matrix

The 1~9 scale method (Table 3) was cited to construct the judgment matrices for qualitative factors, and a mathematical transformation method was used to construct the judgment matrices for quantitative factors.

According the relative importance of each indicator belonged to criteria p,

$$G = (g_{uv})_{q\times q} \qquad u, v = 1, 2, \cdots, n$$

Table 3 Scale description

Scale	1	3	5	7	9	2,4,6,8
Description	Equally important	Slightly important	Quite important	Obviously important	Absolutely important	Between adjacent importance

2) According to the judgment matrix to solve the index weight

The comparison can be made to a number of 2×2 judgment matrix, and then solve the maximum eigenvalue of the judgment matrix. The corresponding feature vectors are normalized, this normalized result is the weight of each index.

Both direct solving method and approximate solution methods (such as root mean square method, power method, and product method etc.) are usually used from practice. Root mean square method is used in this study, the weight of index t belonged to criteria p is

$$w_{pt} = \frac{\sqrt[p]{\prod_{v=1}^{p} g_{tv}}}{\sum_{u=1}^{p} \sqrt[p]{\prod_{v=1}^{p} g_{uv}}} \qquad t,\ p, u, v = 1, 2, \cdots, n;\ 1 \leqslant t \leqslant q,\ 1 \leqslant u \leqslant q,\ 1 \leqslant v \leqslant q \tag{7}$$

The weight vector of all indexes belonged to criteria p is

$$\boldsymbol{W}_p = [w_{p1}, w_{p2}, \cdots, w_{pt}, \cdots, w_{pq}]^{\mathrm{T}} \qquad t, p, q = 1, 2, \cdots, n;\ 1 \leqslant t \leqslant q \tag{8}$$

3) Consistency test of judgment matrix

The complexity of the objective things and the diversity of people's understanding, will inevitably cause one-sidedness. It means that each judgment matrix has possibility of inconsistent[12]. Consistency checking of matrices is introduced as

$$C.R. = C.I./R.I. \tag{9}$$

Among them,

$$C.I. = (\lambda_{\max} - n)/(n - 1) \tag{10}$$

When $C.R. \leqslant 0.1$, the judgment matrix could be considered as consistency; otherwise, the judgment matrix shoud be readjusted. Average random consistency index $R.I.$ is depended on the value of n. For the 1~9 order matrix, the value of $R.I.$ are shown in Table 4.

Table 4 The value of the average random consistency index *R.I.*

n	1	2	3	4	5	6	7	8	9
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3.4 Risk evaluation model

The risk evulation result of criteria p is

$$R_p = K_p \times W_p = \sum_{t=1}^{q} k_{pt} w_{pt} \tag{11}$$

So, the risk evulation result of man subsystem is

$$R_{B_1} = K_{B_1} \times W_{B_1} = \sum_{t=1}^{5} k_{1t} w_{1t} \tag{12}$$

The risk evulation result of machine subsystem is

$$R_{B_2} = K_{B_2} \times W_{B_2} = \sum_{t=1}^{3} k_{2t} w_{2t} \tag{13}$$

For natural environment:

$$R_{c_{31}} = K_{c_{31}} \times W_{c_{31}} = \sum_{t=1}^{3} k_{31t} w_{31t} \tag{14}$$

For social environment:

$$R_{c_{32}} = K_{c_{32}} \times W_{c_{32}} = \sum_{t=1}^{3} k_{32t} w_{32t} \tag{15}$$

For management environment:

$$R_{c_{33}} = K_{c_{33}} \times W_{c_{33}} = \sum_{t=1}^{4} k_{33t} w_{33t} \tag{16}$$

The risk evulation result of environment subsystem:

$$R_{B_3} = [R_{c_{31}}, R_{c_{32}}, R_{c_{33}}] \times W_{B_3} \tag{17}$$

The risk evulation result of man-machine-environment system:

$$R_A = [R_{B_1}, R_{B_2}, R_{B_3}] \times W_A \tag{18}$$

4 Case analysis

4.1 Expert scoring

To evaluate the safety risk of a field operation task, five experts, *i.e.*, e_1, …, e_5, are invited to investigate the safety risk. Each expert scores every evaluation index at the bottom level. The score "1, 2, 3, 4, 5" denote "basically no risk, accepted risk, obvious risk, major risk, and considerable risk", respectively. Table 5 illustrates the score results.

Table 5 Original expert evulate score

	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{21}	c_{22}	c_{23}	d_{311}	d_{312}	d_{313}	d_{321}	d_{322}	d_{323}	d_{331}	d_{332}	d_{333}	d_{334}
e_1	1	1	1	1	2	1	1	1	2	2	1	1	2	1	1	1	1	1
e_2	1	1	2	1	2	1	1	2	2	3	1	1	2	1	2	2	1	2
e_3	1	1	1	1	3	2	1	1	3	2	2	2	1	2	2	1	1	1
e_4	2	1	1	2	2	1	2	1	3	3	1	1	1	1	1	2	1	2
e_5	2	2	1	1	2	1	2	2	2	3	1	1	1	1	2	1	2	1

4.2 Index score processing

Given the fact that five experts are investigated to score each index, an integrated opinion based on the five experts' opinions should be considered. Based on the Table 2 and each expert's experience and ability, the evaluating weight of each element is presented using the bracketed number on Table 6.

Table 6 Expert weight calculation result

Expert	F_1	F_2	F_3	F_4	Accumulated weight	Normalized weight
e_1	Senior engineer(0. 45)	15(0. 42)	Very familiar(0. 36)	Very familiar(0. 45)	1. 68	0. 24
e_2	Senior engineer(0. 45)	9(0. 33)	Very familiar(0. 36)	Familiar(0. 27)	1. 44	0. 21
e_3	Engineer(0. 27)	12(0. 42)	Very familiar(0. 36)	Very familiar(0. 45)	1. 5	0. 22
e_4	Engineer(0. 27)	6(0. 33)	Familiar(0. 29)	Very familiar(0. 45)	1. 34	0. 19
e_5	Operator(0. 09)	4(0. 17)	Familiar(0. 29)	Very familiar(0. 45)	1	0. 14

According to the equation 3, in this evaluation task, the comprehensive weight of each expert is shown in the "Normalized weight" column, *i.e.*, $W^e = [0.24, 0.21, 0.22, 0.19, 0.14]$

According to the equation 6 and the equation 7, the final expert score result for each index is shown in Table 7.

Table 7 The final expert score result for each lowest index

	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{21}	c_{22}	c_{23}	d_{311}	d_{312}	d_{313}	d_{321}	d_{322}	d_{323}	d_{331}	d_{332}	d_{333}	d_{334}
e'	1.330	1.140	1.210	1.190	2.220	1.220	1.330	1.350	2.410	2.540	1.220	1.220	1.450	1.220	1.570	1.400	1.140	1.400

Based on the Table 7, we can conclude that:

$$K_{B_1} = [1.330,\ 1.140,\ 1.210,\ 1.190,\ 2.220]$$

$$K_{B_2} = [1.220,\ 1.330,\ 1.350]$$

$$K_{c_{31}} = [2.410,\ 2.540,\ 1.220]$$

$$K_{c_{32}} = [1.220,\ 1.450,\ 1.220]$$

$$K_{c_{33}} = [1.570,\ 1.400,\ 1.140,\ 1.400]$$

4.3 Weight calculation

Based on the analytic hierarchy process (AHP), the experts are invited to score each index, thereby constructing the judgment matrix, and calculating the weight set of each index relative to the indexes at the superior level.

Table 8 The judgment matrix and calculation results

(1)No	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)No	(11)	(12)	(13)	(14)	(15)	(16)	(17)
1	A	B_1	B_2	B_3	—	—	$w^{(A)}$	$C.R.$	19	c_{31}	d_{311}	d_{312}	d_{313}	—	$w^{(C31)}$	$C.R.$
2	B_1	1	2	4	—	—	0.571		20	d_{311}	1	1/3	2	—	0.249	
3	B_2	1/2	1	2	—	—	0.286	0	21	d_{312}	3	1	3	—	0.594	0.081
4	B_3	1/4	1/2	1	—	—	0.143		22	d_{313}	1/2	1/3	1	—	0.157	
5	B_1	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	$w^{(B1)}$	$C.R.$	23	c_{32}	d_{321}	d_{322}	d_{323}	—	$w^{(C32)}$	$C.R.$
6	C_{11}	1	4	2	5	3	0.445		24	d_{321}	1	1/2	1	—	0.250	
7	C_{12}	1/4	1	1/2	1	1/2	0.098		25	d_{322}	2	1	2	—	0.500	0
8	C_{13}	1/2	2	1	2	1	0.196	0.077	26	d_{323}	1	1/2	1	—	0.250	
9	C_{14}	1/5	1	1/2	1	2	0.124		27	c_{33}	d_{331}	d_{332}	d_{333}	d_{334}	$w^{(C33)}$	$C.R.$
10	C_{15}	1/3	2	1	1/2	1	0.137		28	d_{331}	1	1/2	1/3	1	0.141	
11	B_2	C_{21}	C_{22}	C_{23}	—	—	$w^{(B2)}$	$C.R.$	29	d_{332}	2	1	1/2	2	0.263	0.041
12	C_{21}	1	2	1/2	—	—	0.286		30	d_{333}	3	2	1	3	0.455	
13	C_{22}	1/2	1	1/4	—	—	0.143	0	31	d_{334}	1	1/2	1/3	1	0.141	
14	C_{23}	2	4	1	—	—	0.571									
15	B_3	C_{31}	C_{32}	C_{33}	—	—	$w^{(B3)}$									
16	C_{31}	1	3	1/3	—	—	0.258									
17	C_{32}	1/3	1	1/5	—	—	0.105	0.062								
18	C_{33}	3	5	1	—	—	0.637									

Based on the rational analysis of existing literature and expert opinion, the relative importance degrees of the three criteria, i.e., "man B_1", "machine B_2", "environment B_3", are shown on the Table 8 (Row: 1~4; Column: 2~5). According to the Table 8, the weights of B_1, B_2, B_3 relative to A are illustrated on the Table 8

(Row: 2~4; Column: 8). Corresponding $CR=0<0.1$, indicating that the weight assignment can pass the test.

As shown on the Table 8, in terms of the weight of each index, the consistency test is in the acceptable range.

$$\boldsymbol{W}_A = [0.571, 0.286, 0.143]^T$$

$$\boldsymbol{W}_{B_1} = [0.445, 0.098, 0.196, 0.124, 0.137]^T$$

$$\boldsymbol{W}_{B_2} = [0.286, 0.143, 0.571]^T$$

$$\boldsymbol{W}_{B_3} = [0.258, 0.105, 0.637]^T$$

$$\boldsymbol{W}_{c_{31}} = [0.249, 0.594, 0.157]^T$$

$$\boldsymbol{W}_{c_{32}} = [0.250, 0.500, 0.250]^T$$

$$\boldsymbol{W}_{c_{33}} = [0.141, 0.263, 0.455, 0.141]^T$$

4.4 The integrated evaluation result

For man subsystem: $R_{B_1}=K_{B_1}\times\boldsymbol{W}_{B_1}=1.393$

Similarly, for machine subsystem: $R_{B_2}=1.310$

For natural environment: $R_{c_{31}}=2.300$

For social environment: $R_{c_{32}}=1.335$

For management environment: $R_{c_{33}}=1.306$

For environment subsystem: $R_{B_3}=1.566$

For man-machine-environment system: $R_A=1.394$

4.5 Evaluation result analysis

Based on the evaluation results above, we can find that:

1) The integrated evaluation result of man-machine-environment system is 1.394, which is located between the "Negligible risk" and "Accepted risk", indicating that the safety risk is acceptable.

2) The corresponding safety risk on subsystem of individual man, machine, and environment subsystem is located between the "Negligible risk" and the "Accepted risk". The risk degree from least to great is environment subsystem, man subsystem, and machine subsystem, which indicates that environment has the greatest impact on this risk evaluation task.

3) In the machine subsystem, natural environment has the largest risk (2.300), which is located between the "Accepted risk" and "Obvious risk". The "topographic features" and "meteorology and hydrology" present the obvious risk, mainly because that on one hand, the task area is in the plateau region, the rugged road due to the terrain leads to a certain risk of machine operation, entailing more advanced vehicle maintenance and drivers management. On the other hand, the low temperature outdoor is prone to lead to the cracking of bare pipeline machine, thus good protection of equipment key parts is required.

4) The risk evaluation of each index at the index layer is as follows: "safety concept" in the man subsystem has the greatest risk (2.220), which is located between the "Accepted risk" and "Obvious risk". Other indexes are normal. This indicates that equipment operators in the mission team have strong ability and skill. However, the long-term safe condition has reduced the risk prevention awareness for some operators. Therefore, it is necessary to carry out some management activities, such as safety culture promotion, risk management training, to enhance the personal safety concept.

5 Conclusion

1) A man-machine-environment system evaluation model is proposed for the safety risk of large field work project.

2) Applying the model to the task safety risk assessment of a field work project, the comprehensive evaluation result of the man-machine-environment system is between the "Negligible risk" and "Acceptable risk".

3) The risk of each subsystem (man, machine and environment) is also between the "Negligible risk" and "Acceptable risk". Relatively, the risk of environment subsystem is slightly higher mainly because that bumpy roads and low temperature environment of plateau region could cause equipment accident. In addition, there is a certain risk of safety concept index of man subsystem, and the safety concept education and training need to be strengthened.

From the perspective of man-machine-environment system, this safety risk assessment method makes the risk assessment for large scale field work projects more scientific by transferring the risk from the machine subsystem to the man subsystem and the environment subsystem, and quantitative analysis on the risk value of human machine environment and its index layer. However, due to the different nature of the task, in practical application, some indicators of the evaluation index system need to be combined with further revision, while the weight of the index may also need to be reconfigured in reality.

References

[1] Gao J, Song S G, Wu P. Identification and risk assessment of dangerous and harmful factors in natural gas mining [J]. China Safety Science and Technology, 2011, 7 (11): 57-62 (in Chinese)

[2] Wang L Y, Wang L, Huang C. Environmental risk analysis of natural gas drilling[J].Mining Safety and Environmental Protection, 2005, 32(4):19-22 (in Chinese)

[3] Wang S H, Wang H. Experience of safety risk management and control for large scale frame beam project[J]. Dual Use Technologies & Products, 2014,(13):171 (in Chinese)

[4] Yin Z S. Discussion on the application of risk assessment technology [J]. Western China Exploration

Engineering, 2008, 20 (11): 259-261 (in Chinese)

[5] Wang Q X, Chen C, Liu Y, et al. Construction of safety risk management and control system for field work [J]. Electric Power Safety Technology, 2011, 13 (7): 14-17 (in Chinese)

[6] Wang B, Yang X Y, Zhao C L, et al. On site risk assessment of drilling operation based on Bayesian network [J]. Journal of Southwest Petroleum University, 2015, 37 (2): 131-137 (in Chinese)

[7] Qin Y T, Cao W Q, Li D K. Low temperature gas dynamic valve man-machine environment reliability evaluation method [J]. Rocket Propulsion, 2014,40 (2): 82-89 (in Chinese)

[8] Chen T Z, Du M H, Xue L, et al. The role of man machine environment system engineering in joint operations at sea[J]. Science & Technology Vision, 2016, (14):309-310 (in Chinese)

[9] Zuo B L, Zhang J X, Xu H J. The fuzzy comprehensive evaluation of air traffic control safety of human machine environment engineering [J]. Fire Control & Command Control, 2016,2(2):60-64 (in Chinese)

[10] Xu K Q, Cui K, Wu D G. Risk assessment of railway transportation of military hazardous articles based on man-machine-environment system engineering[J]. Journal of Academy of Military Transportation, 2009,11(3): 18-21 (in Chinese)

[11] Holicky M. Probabilistic risk optimization of road tunnels[J]. Structural Safety, 2009, 31(3): 260-266

[12] Zhang Y L, Chi G T, Zhu Z C. The economic evaluation model based on coefficient of variation and-AHP and an empirical research during the 10th five-year of china [J]. Management Review, 2011 (1): 3-13 (in Chinese)

Brief Biographies

JIANG Wei-yang is a Ph. D. and iecturer, Xi'an Institute of High Technology and Science. His research interests include security risk assessment and project managerment. jwy126@ 126.com

ZHAO Man-yun is an associate professor,Xi'an Institute of High Technology and Science.His research interests include risk management and contingency management.

ZHANG Lian is a lecturer, Xi'an Institute of High Technology and Science. His research interests include security management and leadership science.

SONG Wei-dong, in the security management office, Xi'an Institute of High Technology and Science. His research interests include accident prevention and policy management.