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Evaluation of workplace safety performance in the Chinese petroleum industry

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Abstract: Reform of the Chinese petroleum industry has entered its second phase since early 1999. The productivity of the petroleum industry has been greatly improved, while the safety performance and records are not satisfactory. This paper investigates the critical factors for improving safety performance in the Chinese petroleum industry. The data used for the analysis are from a questionnaire survey administered to 480 professionals in the petroleum industry in which 143 valid responses were received. Statistical analysis techniques are used to analyze the data collected. The findings revealed that the most significant source of the safety problem is due to the combination of several reasons, including (a) violation on operating procedures, (b) obsolete facilities and equipment failures, (c) insufficient safety management system, (d) improper commands, number of casualties, and (e) production performances and operating skills. The three most essential protective methods include safety training and increasing staff's safety consciousness, cultivating safety culture, and enhancing equipment management and detecting hazards in time.

Keywords: safety factors, protective methods, correlation analysis, petroleum industry, safety management

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1 Introduction

There are various factors influencing safety in the industrial practice, particularly in the process of implementing petroleum projects. Industrial practitioners always feel confused on the identification of most significant factors that affect safety performance in the practice. Many employees who work in the petroleum projects have suffered from various catastrophic accidents. For instance, there were 125 accidents which resulted in the death of 533 people in the petroleum industry in China and USA in 2012 (Du et al. 2013). The consequence of petroleum project accidents can also create nuisance to the environment. Poisonous and corrosive chemicals released from petrol accidents will not only harm people's health but also bring environmental damage such as gas pollution (Wu 2007). For example, Gasikule oilfield in Qaidam basin led serious underground pollution due to blowout and surface-emitting oil accidents in 2003. Solid materials containing pure and polluted oil leaked harm the surrounding soil that causes desertification and extensive deaths of wild lives (Zhao et al. 2003). Therefore, analyzing the important degree of different safety factors can help both the working and managerial staff to understand the safety issue in the petroleum projects and take corresponding protective measures.

With proper understanding of safety factors in the petroleum projects, managers in petroleum business can take adequate measures to supervise and improve the whole production process so that the damage to precious materials can be reduced and organizational reputation can be upheld.

There are various existing studies on the subject of safety management and performance on the petroleum projects (Aven and Vinnem 2007). These studies can be classified into two groups: one with the focus on the investigation of safety problem and managerial methods, and the other with the focus on case studies. Yu et al. (2015) proposed an elaborate security assessment system for petroleum projects which took 16 safety factors such as standard operation, mechanical integrity, selection of contractors, contingency management, and so on into account to improve the management level of process safety in domestic enterprises. Wang (2015) paid more attention on enhancing humanized management, safety awareness, proper distribution, and completion of safety production structure. The problem of being scarce in professional team for safety management in petroleum corporations was put forward by Tang (2016), where a safe production environment established would bring beneficial effects on petroleum companies. Song (2014) suggested several measures for improving safety performance in the petroleum projects, such as improving the qualities of staff and strengthening frequent daily safety check. Thinking of enterprise security concept and its significance, Gao (2011) explained that well-organized management and perfect protection methods are becoming much more imperative and effective in petroleum projects. Yang (2013) stated that humanized management policies implemented in petroleum projects would contribute to safety in production. Progress in safety management and the unity of managers and staff play an essential role in the safety of petroleum business. In addition, Qian (2016) presented four tail-made suggestions to the safety risk management of underground petroleum projects in China: (a) establishment of laws and regulations, (b) implementation of safety risk management system, (c) foundation of decision support systems, and (d) forecasting and controlling measures for major accidents in underground engineering. Two inevitable uncertainties such as unpredictable causes and shortage of proper tools in nuclear power plant projects were pointed out by Hoo and Yang (2016), and the computerized system was expected to assist project managers in monitoring, tracking, and controlling potential impacts of risk events. As fuels in petroleum stations are flammable liquids, protection concepts are needed for their transport, use, and shortage and for the operation. Considering safety characteristics of petroleum mixtures such as flash points and upper explosion points, Brandes (2009) proved that protection concepts are still reliable nowadays. After considering direct and indirect factors such as environmental corrosion and leakage of tubes which influenced the conflagration in one oilfield in 2011, Qiu and Gao (2013) suggested that security alarm system and employees responding to risk should be strengthened. By consecutive analysis of three impressive petroleum accidents in USA and China, Huang (2007) focused on the importance of facilities updated for easier operation and stricter supervision from managers. The accidents of petroleum projects can be divided into four major categories, including (a) fall from a height, (b) electric shock, (c) fire, and (d) vehicle damage (Xu and Su 2011). However, the literature did not cover the key factors affecting the safety performance in the petroleum projects.

Therefore, this paper aims to identify the critical factors improving safety performance and recommend the most important safety management measures within the context of the Chinese petroleum industry.

2 Research methodologies

The raw data for analysis in this study are collected from a questionnaire survey to examine the severity of safety factors in relation to the petroleum projects. The questionnaire comprised 32 safety factors and 13 safety measures as identified from the literature. The factors are across seven categories, including (a) staff's unsafe behavior, (b) unsafe working conditions, (c) management negligence, (d) safety performance assessment, (e) factors for selecting managerial staff, (f) staff's annual appraisal and bonus distribution, and (g) selection of contractors. The 32 safety factors and the 13 safety measures are listed in Tables 1 and 2, respectively.

The questionnaire was divided into three sections: (1) culture of safety management system, mechanism design, resource allocation, and other aspects of the "safety first, prevention-oriented" thinking; (2) its use of resource discovery and governance and ability of safety hazards; and (3) its implementation of operational procedures and ability to achieve post-safety measures. Respondents were the employees from China National Petroleum Corporation, Southwest Oil and Gas Field Branch. Three levels of employees were involved in the survey: (1) managerial departmental officers; (2) baseline production and safety management cadres; and (3) frontline workers. All levels of respondents had at least 5 years of safety-related experience. The questionnaire survey was conducted between October 2016 and December 2016. A 5-point Likert scale was used for the questionnaire survey to examine respondents' relevant importance of the questions.

In total, 480 questionnaires were distributed to various professionals in petroleum business, and 143 effective responses were received. Correlation analysis was used to undertake data processing and identify the critical key factors in relation to the safety issue in the petroleum projects.

Tab. 1: Safety factors in implementing petroleum projects.

Staff's unsafe behaviors	**Safety performance assessment**
F1: Violation on operating procedures	F17: Number of casualties
F2: Not wearing safety uniforms	F18: Damage of key equipments
F3: Negativities and distractions from safety attention	F19: Injury rate per 1,000 people
F4: Poor safety consciousness	F20: Work loss rate per million hours
F5: Lack of safety skills	F21: Staff participation rate for safety management
Unsafe working conditions	**Factors for selecting managerial staff**
F6: Obsolete facilities and equipment failures	F22: Production performances and operating skills
F7: Outdated techniques	F23: HSE risk management ability
F8: Lack of safety protection and damage of safety accessories	F24: Political quality
F9: Unsafe working environment	**Staff's annual appraisal and bonus distribution**
Management negligence	F25: Quantifiable workload or turnover
F10: Insufficient safety management system	F26: Safety performance
F11: Insufficient supervision	F27: Participation performance in safety management
F12: Improper operating procedures	**Selection of contractors**
F13: Low safety awareness of managerial staff	F28: Qualification grades and safety production license
F14: Insufficient investment in safety	F29: Compensation for injury in the past 3 years
F15: Poor communication for safety messages	F30: Accident rates
F16: Improper commands	F31: Legal disputes
	F32: Performance of successful safety management

Tab. 2: Safety measures for improving safety performance in petroleum projects.

Improvement in people's safety behaviors	M6: Investment in safety
M1: Safety training and increasing staff's safety consciousness	M7: Updating safety techniques and facilities
M2: Improving safety communication and raising management ability	**Improving safety management standard**
M3: Provision of welfare to employees	M8: Improving HSE system
M4: Cultivating safety culture	M9: Strengthening supervision on safety
Better equipment and facilities	M10: Regular inspection on potential safety risks
M5: Enhancing equipment management and detecting hazards in time	M11: Increasing safety investment
	M12: Implementing regular safety training programs
	M13: Effective incentive policy

3 Research data

3.1 Responses on the importance of safety factors

Table 3 summarizes the number of respondents who gave different ratings to the factors as identified in the literature.

3.2 Responses on the importance of safety measures

Table 4 summarizes the number of respondents who gave different grades of importance to different safety measures.

4 Data analysis

4.1 Statistics results of the safety factors and safety measures

Using the statistical analysis, the research data are first examined using the parameter covariance. It aims to identify the significance of the factors in relation to the safety performance of the petroleum projects. Second, the correlation coefficient is adopted to further study the correlations between the critical factors. The findings can be useful for the managerial level to implement and improve the safety measures. The statistical analysis of the mean and variance is summarized in Tables 5 and 6. Table 5 summarizes the analysis results of the safety factors. It can

Tab. 3: Responses on the importance of safety factors.

Code	Less significant ←			More significant →		Total score
	1	2	3	4	5	
F1	1	0	7	9	126	688
F2	1	21	39	47	35	523
F3	8	9	31	55	40	539
F4	2	8	24	48	61	587
F5	4	7	34	46	52	564
F6	2	2	20	38	81	623
F7	8	16	36	46	37	517
F8	1	7	17	54	64	602
F9	1	16	41	45	40	536
F10	3	5	37	49	49	565
F11	0	3	11	26	103	658
F12	2	23	30	50	38	528
F13	2	12	34	49	46	554
F14	8	19	46	47	23	487
F15	7	25	46	38	27	482
F16	4	6	13	21	99	634
F17	6	5	14	31	87	617
F18	7	6	40	53	37	536
F19	6	15	26	41	55	553
F20	3	18	33	39	50	544
F21	5	14	33	43	48	544
F22	0	3	30	46	64	600
F23	0	4	21	51	67	610
F24	10	17	34	41	41	515
F25	2	13	28	48	52	564
F26	4	6	28	51	54	574
F27	2	8	51	27	55	554
F28	3	3	21	34	82	618
F29	7	15	37	49	35	519
F30	1	10	28	47	57	578
F31	4	17	36	47	39	529
F32	5	6	23	52	57	579

Tab. 4: Responses on the importance of safety measures.

Code	Less significant ←			More significant →		Total score
	1	2	3	4	5	
M1	0	3	15	36	89	640
M2	0	2	23	68	50	595
M3	3	20	55	39	26	494
M4	1	10	35	49	48	562
M5	1	2	16	45	79	628
M6	0	6	22	53	62	600
M7	2	14	26	62	39	551
M8	0	6	42	37	58	576
M9	0	6	23	50	64	601
M10	2	8	33	53	47	564
M11	0	3	31	49	60	595
M12	2	11	47	47	36	533
M13	6	8	34	44	51	555

be found that the variance values for the factors are significantly high. The significant differences of the responses from respondents are appreciated as they have different experiences and work under different circumstances. Therefore, the ranking between the 32 factors is established by using the parameter covariance, $\frac{\mu}{\sigma}$ where μ is the sample mean and σ is the sample standard deviation.

Tab. 5: Statistical analysis of the safety influencing factors.

Code	μ	σ^2	$\frac{\mu}{\sigma}$	Rank
F1	4.811189	0.33498	8.31272	1
F2	3.657343	1.050418	3.568491	21
F3	3.769231	1.198494	3.442983	22
F4	4.104895	0.933053	4.249608	9
F5	3.944056	1.045821	3.856686	16
F6	4.356643	0.760917	4.994399	5
F7	3.615385	1.313609	3.154433	30
F8	4.20979	0.781163	4.763099	6
F9	3.748252	1.013546	3.72312	19
F10	3.951049	0.927674	4.102181	11
F11	4.601399	0.519439	6.384439	2
F12	3.692308	1.150081	3.442974	23
F13	3.874126	1.005135	3.864218	15
F14	3.405594	1.164165	3.156354	29
F15	3.370629	1.254242	3.00968	31
F16	4.433566	1.014817	4.40108	8
F17	4.314685	1.124749	4.068378	12
F18	3.748252	1.083476	3.600967	20
F19	3.867133	1.345983	3.333261	27
F20	3.804196	1.234388	3.424026	25
F21	3.804196	1.234388	3.424026	26
F22	4.195804	0.702919	5.00452	4
F23	4.265734	0.656658	5.2641	3
F24	3.601399	1.470488	2.969891	32
F25	3.944056	1.045821	3.856686	17
F26	4.013986	0.992811	4.028492	13
F27	3.874126	1.075065	3.736426	18
F28	4.321678	0.88953	4.58218	7
F29	3.629371	1.22627	3.277466	28
F30	4.041958	0.935302	4.179418	10
F31	3.699301	1.161328	3.43275	24
F32	4.048951	1.039562	3.97116	14

Similarly, Table 6 summarizes the analysis results of the safety measures, and the ranking results are also identified by using the parameter covariance $\frac{\mu}{\sigma}$.

4.2 Correlation analysis

To examine the important safety factors, the top 15 safety factors are selected for further analysis by using correlation analysis technique. The correlation analysis will help understand the relevance between these 15 factors. This understanding will help confirm the critical safety factors. By using the data given in Table 5, the correlation analysis of the top 15 factors is calculated, and the results are summarized in Table 7.

A previous study suggested that two factors have no relevance if their correlation coefficient assumes a value of <0.3, weak relevance with the coefficient value of 0.3–0.5, significant relevance with the coefficient value of 0.5–0.8, and strong relevance with the value of >0.8 (Cohen et al. 2013). Theoretically, 0.5 should be adopted for the threshold based on the literature. However, after carefully analyzing the data and results from this study, 0.4 has been selected as threshold for judging whether two or more factors are significantly correlated due to a clear gap between the values for weak relevance and significant relevance. By using this threshold, only the factors such as F1, F17, and F32 are independent. Other factors have different relevance between each other, in which F6, F10, F16, and F22 have less relevance to others. As a result, factors such as F1, F6, F10, F16, F17, F22, and F32 are considered critical safety factors.

Similarly, correlation analysis of safety management measures is conducted to understand the relevance between the top 10 measures. This understanding will help confirm the most effective measures. By using the data given in Table 4, the correlation analysis of the top 10 safety measures is calculated, and the results are summarized in Table 8.

By using the value 0.4 as the threshold of correlation coefficient to judge whether two or more measures are significantly correlated, measures such as M1, M4, and M5 are considered critical safety management measures.

Tab. 6: Statistical analysis of the safety measures for improving safety management.

Code	μ	σ^2	$\frac{\mu}{\sigma}$	Rank
M1	4.475524	0.585065	5.851157	1
M2	4.160839	0.540564	5.659229	2
M3	3.454545	1.017165	3.425274	13
M4	3.93007	0.918187	4.101425	9
M5	4.391608	0.62986	5.533523	3
M6	4.195804	0.716905	4.955463	5
M7	3.853147	0.950462	3.952284	10
M8	4.027972	0.86635	4.327526	7
M9	4.202797	0.735097	4.901919	6
M10	3.944056	0.905961	4.1437	8
M11	4.160839	0.69441	4.993129	4
M12	3.727273	0.939606	3.845195	11
M13	3.881119	1.181671	3.570332	12

5 Discussion

From the analysis results generated in the "Data analysis" section, the critical safety factors, such as F1: violation on operating procedures, F6: obsolete facilities and equipment failures, F10: insufficient safety management system, F16: improper commands, F17: number of casualties, F22: production performances and operating skills, and F32: performance of successful safety management, are identified as the most impressive factors in petroleum

Tab. 7: Correlation analysis between the 15 important safety factors.

	1	4	6	8	10	11	13	16	17	22	23	26	28	30	32
1	1														
4	0.101	1													
6	0.381	0.3	1												
8	0.201	0.455	0.369	1											
10	0.201	0.299	0.288	0.292	1										
11	0.138	0.394	0.304	0.338	0.443	1									
13	0.116	0.495	0.174	0.33	0.399	0.425	1								
16	0.241	0.307	0.212	0.423	0.083	0.148	0.276	1							
17	0.06	0.087	0.066	0.23	0.072	0.221	0.2	0.363	1						
22	0.228	0.265	0.328	0.217	0.193	0.286	0.259	0.155	0.202	1					
23	0.206	0.277	0.37	0.316	0.339	0.352	0.338	0.317	0.093	0.285	1				
26	0.087	0.355	0.24	0.431	0.387	0.369	0.349	0.221	0.142	0.154	0.451	1			
28	0.275	0.31	0.471	0.328	0.192	0.33	0.176	0.252	0.182	0.442	0.373	0.294	1		
30	0.163	0.361	0.33	0.518	0.313	0.386	0.462	0.257	0.232	0.317	0.416	0.47	0.253	1	
32	0.041	0.179	0.075	0.098	0.223	0.247	0.346	0.061	0.134	0.265	0.276	0.354	0.056	0.237	1

Tab. 8: Correlation analysis between the 10 important safety management measures.

	1	2	4	5	6	7	8	9	10	11
1	1									
2	0.402	1								
4	0.04	0.208	1							
5	0.348	0.353	0.173	1						
6	0.31	0.38	0.387	0.379	1					
7	0.204	0.43	0.341	0.276	0.513	1				
8	0.474	0.329	0.64	0.398	0.308	0.16	1			
9	0.231	0.378	0.395	0.287	0.437	0.358	0.163	1		
10	0.34	0.537	0.333	0.44	0.457	0.416	0.401	0.459	1	
11	0.28	0.468	0.355	0.427	0.544	0.403	0.28	0.409	0.603	1

projects. The managerial staff in petroleum business realize that staff's improper behaviors, unsafe working conditions, management negligence, and unprofessional management ability can bring catastrophic outcomes to them and the environment, including enormous explosive and massive destruction. This has also been pointed out in previous studies. An operator in Jilin Chemical industry violated the operation procedures and did not switch off the steam valve, causing the material in preheater to vaporate. Consequently, heating the steam during the production procedure further lead to sudden temperature raise in heater. With the huge explosion in 2005, eight workers died directly and factory suffered from significant damage and heavy economic loss. In August 2014, contractors intended to promote the process of petroleum projects in Lu Keqin oil factory and then forced illegal mining blindly which caused severe destruction of oil pipelines. Contractors' unsafe behaviors and loose supervising managements were to blame. Taking another example, a fire accident was caused by oil spill in Changqing oil field in 2014 and lax safety supervision and the lack of HSE risk management capacity took the responsibility which proved the results significantly.

In referring to safety management measures, there are numerous protective methods introduced to strengthen safety management capacity. As described in the "Data analysis" section, the most important measures are suggested as M1, M4, and M5: safety training and increasing staff's safety consciousness, cultivating safety culture, and enhancing equipment management and detecting hazards in time. Due to the limited funds, shortage of human resources and time constraints, petroleum companies usually cannot afford to promote all those protective measures. However, they can implement some targeted measures which not only help petroleum companies achieve maximum efficiency but also assist them to save budget with the data supplied before. Management should contribute more resources particularly to raising safety consciousness across the organization. The culture of total safety management should be promoted, which requests for the participation of not only workers but also management staff, project clients, and government officials.

Management staff in petroleum companies should address these key safety factors by applying these effective management measures in implementing petroleum projects. For example, to deal with the problem of works' unsafe behavior, companies can organize regular safety training according to different positions and evaluate employees' safety awareness. Better safety culture can be educated through introducing incentive mechanism by rewarding those staff who are evaluated as good safety performance colleagues and applying penalties to those staff who are evaluated as poor safety performers. As for the factor of insufficient supervision, training programs on how to supervise safety performance can also be introduced to these managerial staff who assume the role of supervision. It is considered important to implement formal training programs for producing qualified safety management professionals and recruit them in various petroleum companies. On the other hand, effective communications should be promoted between workers and management, which can serve as a counterparty surveillance measure not only between workers and management staff but also among all organization staff themselves. Experience sharing should be promoted between organizations; thus, good safety management methods or practices within the whole petroleum industry can be promoted, which can contribute to the improvement in safety performance across the whole industry. Government assumes a key role in mitigating safety risks in petroleum industry by, for example, establishing the rules of implementing risk management system and regulating the risk behaviors of petroleum companies.

6 Conclusion

The paper examined the critical factors for improving safety performance in the Chinese petroleum industry. In addition, the top three important factors, such as violation on operating procedures, number of casualties, and performance of successful safety management are figured out. The most important safety management measures suggested through the survey investigation include (a) safety training and increasing staff's safety consciousness, (b) cultivating safety culture, and (c) enhancing equipment management and detecting hazards in time. The understanding of these findings are of great significance in formulating proper policies within petroleum industry to improve safety performance and providing a reference measures for improving safety performance in the Chinese petroleum industry. The research method adopted in this study can provide a foundation for the research in safety management in other fields, such as transportation industry, machine operation, and handicraft manufacturing. It is appreciated that the findings of this study are based on the data collected with the focus only on petroleum production without considering those factors and management measures associated with petroleum transportation and petroleum stations. The safety management in both petroleum transportation and stations has many challenges as well, and they are highly recommended issues for further research.

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