Human factors analysis of Kaohsiung 8·1 explosion accident based on HFACS-UP

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Abstract. Human factor is one of the main causes of urban gas pipeline explosion accidents. In order to minimize the consequences of such accidents, it is crucial to distinguish the human factors. In the present study, The Human Factors Analysis and Classification System-Urban Pipeline (HFACS-UP) is established according to the characteristics of urban pipeline accidents. Then the HFACS-UP framework is used to identify the human factors of a pipeline explosion accident occurred in Kaohsiung, Taiwan. The results indicate that the routine violations, skill-based errors, intellectual limitations, technological environment, failure to correct problems, insufficient safety culture, organizational process vulnerability and insufficient government supervision are the main factors lead to the explosion accident. Finally, the prevention measures are proposed to ensure the safe operation of urban pipelines based on the analysis results.

1. Introduction
The safety of urban pipeline is closely related to social stability and development. However, the accidents of urban pipeline occurred frequently in recent years, resulting in a large number of casualties and loss of property. For example, the pipeline explosion of Qingdao, Shandong province in China brought 62 deaths, 136 injures and about economic losses of 7.517 billion yuan directly in 2013[1]; a leakage and explosion accident of urban gas pipeline of Songyuan, Jilin caused five deaths, 89 injures and direct economic losses of 44 million yuan in 2017[2]. To determine the causes of pipeline accidents, Zhang[3] conducted that the safety culture construction was weak based on the accident investigation report of Donghuang pipeline in Qingdao, China; Liang et al.[4] pointed out that third-party man-made damage was the main factor of the oil and gas pipeline accidents; Guo et al.[5] identified the risk of third-party man-made damage that threatened the safety of oil and gas pipeline based on Bayesian network; Liu et al.[6] thought that the insufficient management existed in the design, construction and operation stage of pipeline, which resulted in grave consequences[7]; Mou et al.[8] summarized the major pipeline explosion accidents and concluded that the deficiency of safety culture was the root cause. In the present study, the HFACS framework is first modified and HFACS-UP is developed in Section 2 and the practical application is chosen to verify HFACS-UP framework in Section 3. The suggestions are presented in Section 4. The last section presents the main conclusions.
2. Establishment of the HFACS-UP framework

2.1. HFACS description

HFACS framework was proposed by Wiegmann and Shappell\cite{9,10} according to James Reason's Swiss Cheeses model\cite{11,12}. The initially HFACS framework modified from Reason’s Swiss cheese model is expressed in Figure 1. Both Reason’s Swiss cheese model and HFACS framework contain four layers, including unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. As shown in Figure 1, the four layers in HFACS framework are continued analysis and decomposition. Unsafe acts layer is divided into errors and violations. Errors are composed of decision errors, skill-based errors and perceptual errors while the violations composed of routine violations and exceptional violations. The preconditions for unsafe acts contain environmental factors, conditions of the operators, and personnel factors. In respect to the environmental factors, the physical environment and technological environment are chosen. Adverse mental states, adverse physiological states, and physical/mental limitations are considered to belong to the conditions of the operators. Personnel factors are classified into crew resource management and personal readiness. The unsafe supervision includes inadequate supervision, planned inappropriate operations, failure to correct problems and supervisory violations. The resource management, organizational climate, and organizational process are categorized into the fourth layer organizational influence.

2.2. The HFACS-UP framework

The original HFACS framework was designed to obtain the failures associated with aviation accidents. To make the HFACS framework suitable for analysing the pipeline accidents, the modification should be implemented. The modifications are marked in green in Figure 2. The factor “crew resource management” within the “preconditions for unsafe acts” layer is inappropriate to analyse pipeline accidents. For urban gas pipeline accident, the insufficient communication and coordination is one of the factors led to the accidents. Therefore, insufficient communication and coordination took the place of the crew resource management in the modified HFACS. In addition, the external factors of enterprises are not taken into consideration. In the HFACS-UP framework, the social factors such as insufficient government supervision, social economy, laws, regulations, and etc. are considered as the components of the fifth layer.
3. Practical application

3.1. Formatting author names
On July 31, 2014, at around 20:00., residents of Cianjhen District in Taiwan reported a smell of gas. Firefighters arrived about 50 minutes later and found white smoke coming from the gutters at the intersection of Kaixuan 3rd road and Ersheng 1st Road, but did not confirm the location of the eruption. Firefighters identified a flammable gas leak and cordoned off the scene to conduct traffic control, using water mist to dilute the gas, but did not evacuate the surrounding population. The inspectors of the Environmental Protection Bureau and the Firefighters arrived at the Ersheng and Kaixuan intersections at around 21:30 for sampling, and at 21:46 asked for the assistance of the Disaster Response Center of the Tainan Environmental Protection Bureau. During the sampling and leak detection, the area affected by the gas gradually expanded, at 21:50, the Public Works Bureau and the Fire Station informed CDC, CPDC, Taiwan Power and LCY Chemical Corp. The fire station continued to send personnel to carry out rescue. At about 22:22, a gas explosion occurred at No. 9, lane 301, West Street, Qianzhen district. Subsequently, officers of the Disaster Response Center arrived at the scene. At this time the concentration of propylene has been found to exceed the human body's tolerance of nearly 200 times in Ersheng and Kaixuan junction, and 20 minutes later the Fire Commissioner called to inform CDC and CPDC to stop pipeline transmission. Sadly, after 23:56, a series of explosions occurred along the three routes of Kaixuan, Ersheng and Sanduo. The explosions basically ended at 2:00 on August 1, left 32 people dead and 321 injured. The accident scene photos as shown in figure 3.

3.2. Accident analysis results based on HFACS-UP
Unsafe acts:

- Routine violations of the inspector in daily work. Due to the deficiency in maintenance and inspection, the pipeline corrosion and aging cannot be dealt with in time, which lead to pipeline leakage.
• Decision errors of the firefighters. The firefighters judged the leakage gas as “methane gas” (propylene actually) and only diluted the gas with water mist and did not organize the evacuation of people in time.
• Due to the misidentified, the leakage gas, and improperly disposed of the accident scene, the residents’ optimal escape time was delayed, resulting in increased casualties.

Preconditions for unsafe acts:
• Adverse mental states of the inspectors. The inspectors’ working attitude was inappropriate, which caused routine violations. They did not make a serious inspection of the pipeline, just “take a look by the way”.
• Physical/Mental limitations of firefighters. Firefighters not only fail to grasp the physical and chemical properties of the leaked gas, but also do not use the detection equipment, resulting in decision errors. It can be seen that the firefighters lack of position knowledge and skills.

Unsafe supervision:
• Inadequate supervision. The LCY Chemical Corp. responsible for the pipeline operation has not effectively supervised the work of daily pipeline inspectors.
• Failure to correct problem. when a leak is detected and the required pressure check is not carried out, the gas is continued after only half an hour.
• Supervisory violations. The abnormal pressure was not reported to the competent authorities in time, and the gas continued to be transported without any known cause, resulting in the leakage of about 10 tons of propylene.

Organization influences:
• Resource management. The LCY Chemical Corp., which is responsible for the operation of the propylene pipeline, did not carry out the required maintenance and testing of the pipeline, nor did it entrust other units to assist in the maintenance of the pipeline. Inadequate management of equipment resources resulted in serious pipeline aging.
• Organizational climate. The accident enterprises pay attention to production, lack of understanding of safety, in the case of testing and pressure not finished by the owner's request to continue gas transmission.
• Organizational process. The accident enterprises have improperly allocated and managed personnel, and the operators do not have basic knowledge of operation, do not know the operating methods, operating procedures and standard operating procedures of the instruments, and do not have the knowledge and skills required for the post.

Social factors:
• Insufficient government supervision. The supervision and inspection of enterprises is not in place, not timely found in the day-to-day production of the enterprise problems.
• Laws and regulations. There are loopholes in the legal system and standard requirements of enterprise safety in production.
• Others. The overall safety culture of the community needs to be enhanced.

4. Conclusions
(1) Building HFACS-CG framework model. According to the characteristics of gas pipeline accidents in urban areas, the HFACS was amended to replace the second level of "pilot resource management" in the original framework with "communication and coordination among departments and staff", and to add "social factors" to level 5, it includes government regulation, social economy, social law and other factors.
(2) The HFACS-CG framework was used to analyse the human factors and management factors of the explosion accident of the 8ꞏ pipeline in Kaohsiung, Taiwan. The result shows that at the individual level, violations, technical errors, intellectual limitations, and the technical environment are the main accident causes; at the management level, the main causes of the unsafe operation are failure
to correct problems, the lack of management culture and the loopholes in the management process. Lack of government supervision was the main external factor in the pipeline explosion.

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