Study on Influencing Factors of Major Incidents in Petrochemical Parks Based on Bayesian Networks

Haoran Hu¹, Bowen Shao², Jian Guo³*, Bingyuan Hong²*

¹ School of Ships and Maritime, Zhejiang Ocean University, Zhoushan, 316022, China
² School of Petrochemical and Environment, Zhejiang Ocean University, Zhoushan, 316022, China
³ Corresponding author’s e-mail: guojianaaa@163.com, hongby@zjou.edu.cn

Abstract. With the rapid development of the petrochemical industry, the scale of the petrochemical park is gradually expanding. Safety incidents that occur from time to time and their serious consequences cannot be ignored. Based on the systematic summary of chemical incidents in the last 15 years, the main types of incidents are explosion, poisoning and suffocation, and fire. Thus, it is necessary to prevent major incidents from critical events. The incident tree model of major and extraordinarily large explosion incident in petrochemical park is constructed, and it is mapped to a Bayesian network for incident cause analysis and influence analysis. Consequently, it is concluded that illegal command and illegal operations are the main factors leading to the incident. The method of adding a protective layer is proposed to improve its overall safety. It can provide theoretical and technical support for accident risk identification, evaluation, and control in petrochemical park in the future.

1. Introduction

In recent years, major incidents in petrochemical enterprises occur frequently [1]. Moreover, the petrochemical industry has surpassed the coal industry to become the industry with the highest incidence of major incidents. These incidents have not only caused huge casualties and economic losses but also caused serious environmental pollution [2]. The fundamental reason is that the mechanism of chemical accidents is not clear enough. Therefore, the influencing factors of major incidents in the petrochemical park should be analysed emphatically, and the corresponding solutions should be put forward to help the further management of the petrochemical park.

2. Analysis of incident factors

2.1. Statistical analyses of incidents

Based on the statistics of typical incident cases of the State Administration of Work Safety [3], it is concluded that the most important types of chemical incidents in the past 15 years are explosion, poisoning and suffocation, and fire. The incident types are shown in Table 1. According to the "Production Safety Incident Reporting and Investigation and Handling Regulations", incidents are divided into 4 levels: particularly serious incidents, destroyous incidents, major incidents, and general incidents. In the past 15 years, there have been 19 major chemical incidents, most of which were explosion, and one was caused by fire.
Table 1. Incident category statistics

| Incident type                  | Explosion | Poisoning & suffocation | Falling | Leaking | Collapse | Traffic | Fire | Others |
|-------------------------------|-----------|--------------------------|---------|--------|----------|---------|------|--------|
| Number                        | 92        | 39                       | 6       | 10     | 91       | 6       | 11   | 13     |
| Death toll                    | 544       | 126                      | 16      | 26     | 34       | 31      | 33   | 61     |

2.2. *The law of occurrence of major incidents*
Each incident can be divided into two stages: primary and secondary cause [4], such as a gas explosion incident in 2006, the cause was sparks caused by the failure of the power cable two-way junction box; the secondary cause was a gas explosion. As a result, the reason is that the lack of sufficient destructive energy will not directly lead to a major disaster, but it is a triggering condition for the release of energy from a high energy source. According to the definition of the event and its role in the occurrence of the incident, the cause can be called a critical incident [5]. In an incident, the critical incidents are very small, such as damage to the insulation of the power supply cable, causing a short circuit of the core wire, and sparking. Furthermore, the secondary cause stage is the continuation of the small critical incident and the key to the catastrophe. Under the triggering conditions, the destructive energy is directly released, acting on high-density people. Leading to serious consequences of the incident. Therefore, it is necessary to focus on preventing some critical incidents in the chemical industrial park and prevent them from the source to fundamentally reduce the occurrence of incidents.

2.3. *Explosion Incident Tree Analysis*
According to the statistical results, it can be determined that the major chemical incidents in recent years are mainly explosion incidents [6]. By consulting related literature and incident reports[7], the causal factors of major explosion incidents are divided into 23 sub-factors and then using the incident tree model analysis method, the explosion incident is the top event, and the corresponding incident tree is established through the method of Cause-Effect Model [8], as shown in Figure 1.

2.4. *Analysis of causes of Bayesian networks*
The Bayesian network model is a directed graph that contains a conditional probability table. In summary, it intuitively describes the relationship between uncertain system factors through graphs [9].
It can not only infer results through causal factors but also reverse reasoning, which is pushed from the result of the causal factor [10]. In addition, based on the conversion algorithm from the incident tree to the Bayesian network, the constructed incident tree above is mapped to the Bayesian network as shown in Figure 2, and the corresponding Bayesian network model is established to calculate intermediate events and top events probability of occurrence. Through the improved Bayesian network model, the conditional probability table is revised to obtain a more accurate posterior probability and influence of the basic event, to find the most likely way to cause the accident.

![Bayesian network diagram](image)

**Fig. 2.** Bayesian network diagram (Note: see Table 2 for the explanation of symbols in the diagram)

According to the expert score and the method of triangular fuzzy mathematics, the prior probability of the causal factors is obtained, the conditional probability table is improved, and the posterior probabilities of the causal factors are calculated by GENIE software, as shown in Table 2. It can be seen that X25, X31, X32, X33, X34 have higher posterior probabilities, and these causative factors have higher prior probabilities.

| Code | Event name                              | Prior probability | Posterior probability |
|------|-----------------------------------------|-------------------|-----------------------|
| X1   | Exotic fire                             | 0.005             | 0.005                 |
| X2   | Smokes                                  | 0.015             | 0.016                 |
| X3   | Mismanagement                           | 0.02              | 0.021                 |
| X4   | Lightning strike                        | 0.005             | 0.005                 |
| X5   | Design flaws                            | 0.01              | 0.01                  |
| X6   | Equipment damage                        | 0.025             | 0.025                 |
| X7   | Object impact                           | 0.01              | 0.01                  |
| X8   | Use non-explosion-proof tools           | 0.01              | 0.01                  |
| X9   | Rough liquid flow rate                  | 0.005             | 0.005                 |
| X10  | Poor selection                          | 0.01              | 0.01                  |
| X11  | Friction between splashing liquid and air| 0.005             | 0.05                  |
| X12  | No anti-static grounding                | 0.01              | 0.01                  |
| X13  | Ground resistance does not meet the requirements | 0.008             | 0.08                  |
| X14  | Ground resistance is damaged            | 0.005             | 0.005                 |

Table 2. The posterior probability table of basic events
|   | Event Description                                                                 | Probability | Impact |
|---|-----------------------------------------------------------------------------------|-------------|--------|
| X15 | Wear chemical fibre clothes                                                      | 0.005       | 0.005  |
| X16 | Other human body static                                                           | 0.005       | 0.005  |
| X17 | Spontaneous combustion objects such as waste materials stored illegally for a long time | 0.025       | 0.025  |
| X18 | Good heat storage conditions                                                       | 0.008       | 0.008  |
| X19 | Continuous support conditions                                                     | 0.008       | 0.008  |
| X21 | Other combustibles                                                                | 0.015       | 0.02   |
| X22 | Unreasonable design                                                               | 0.02        | 0.021  |
| X23 | Improper selection                                                                | 0.02        | 0.021  |
| X24 | Poor construction and installation quality                                         | 0.015       | 0.016  |
| X25 | The equipment has not been overhauled for a long time                              | 0.035       | 0.039  |
| X26 | Severe weather                                                                     | 0.015       | 0.017  |
| X27 | Equipment overpressure                                                             | 0.015       | 0.017  |
| X28 | No ventilation facilities                                                          | 0.005       | 0.005  |
| X29 | Damaged ventilation facilities                                                     | 0.005       | 0.005  |
| X30 | Not ventilated in time                                                             | 0.005       | 0.005  |
| X31 | Not dealt with in time                                                             | 0.028       | 0.031  |
| X32 | Operation error                                                                   | 0.045       | 0.05   |
| X33 | Illegal command                                                                   | 0.055       | 0.061  |
| X34 | Illegal work                                                                      | 0.062       | 0.068  |
| X35 | Volatilization or liquefaction during normal operation                            | 0.005       | 0.006  |

Impact analysis can determine the importance of an event's impact on the consequence event. Therefore, influence analysis of the Bayesian network is studied to investigate the degree of mutual influence between nodes and find the most likely way to cause the accident. The thickness of the arrow is used in the GENIE software to indicate the influence, as shown in Figure 3. From the results, we can see that the most likely way to cause the event to happen is: X32/X33/X34-M16-M14-M11-M2-T; X21-M2-T, through influence analysis, it can be found that X32, X33, X34, X21 are the most important ways to cause the top event to occur.

2.5. Solutions to reduce accidents

The fundamental purpose of analysing the causal factors of chemical incidents through Bayesian networks is to prevent and control chemical incidents, build an emergency rescue system for the characteristics of chemical incidents. Regarding the constant wear and aging of chemical equipment during operation, the park managers can consider taking measures from several aspects such as safety evaluation of the process, equipment maintenance, and non-destructive monitoring of pipelines. Moreover, the protective layer design is a protective barrier that integrates a series of protective measures in the park to limit the incident to a certain range. Protective embankments, blast walls, and emergency pools in the park are all protective measures. The specific design of the protective layer can refer to the existing technical standards and the actual situation of the petrochemical park.
3. Conclusion

Based on the established Bayesian network model, this paper accurately assesses the quantitative impact of each causal factor on the probability of emergency incidents, uses GENIE software to calculate the posterior probability of each basic event, and conducts impact analysis. As a result, among the posterior probabilities of the causes of explosion incidents, the higher probabilities are long-term failure to overhaul the equipment, failure to handle in time, operating errors, illegal command, and illegal operations; through impact analysis, it can be found when it fits the actual situation, the most likely way to cause the incident. In most chemical incidents, most of them are caused by the state of unsafe people, a few are due to the state of unsafe objects, and some are caused by unsafe environmental factors, which cause these unsafe states to exist. The root cause is management factors. Therefore, chemical enterprise managers should also formulate more complete laws and regulations and strictly implement them to promote the sustainable development of the chemical industry.

Acknowledgments

Industrial Project of Public Technology Research of Zhejiang Province Science and Technology Department (LGG18E040001), and Scientific Research Project of Zhejiang Province Education Department (Y20173854).

References

[1] Li, N., Chen, J. H. (2020) Statistical analysis of dangerous chemicals in China from 2013 to 2019. J. Applied Chemical Industry. 049(005):1261-1265.
[2] Shi, L. C., Wang, R. J., Duo, Y. Q. (2014) Problems and suggestions of safety supervision of dangerous chemicals major hazard in China. J. Journal of Safety Science and Technology. 000(012):161-166.
[3] Sun, S. M., Yu, X. Y., Sun, M. (2018) Statistical Analysis of Chemical Factory Equipment Incident in China during 2000-2017 and Its Countermeasures. J. Sichuan Chemical Industry. 21(4).
[4] Zhou, X. H., Zhong, M. D., Zhao, C. F. (2012) Statistical Analysis of Rules of Extraordinary Big Incidents in China. J. World Sci-Tech R & D. 2011(06):999-1001.
[5] Tian, H. X., Hu, W. J., Luo, C. X. (2020) A study of the key factors, models and countermeasures of national special major incidents. J. Metallurgy and materials. 039(005):58-59.
[6] Nan, X. Z. Z. (2018) Analysis of common causes of fire and explosion incidents in chemical enterprises and preventive measures. J. Safety & Health. 447(03):35-38.
[7] Wang, Z. W., Wang, C. (2020) Research on the Large and Serious Accident Statistics Analysis of Zhejiang Province from 2004 to 2017. J. Industrial Safety and Environmental Protection. 46(4): 41-46.
[8] Zhang, X., Zhu, J. (2020) Analysis on Fire Accident of Airplane based on Fault Tree and Fuzzy Analytical Hierarchy Process. J. Safety. 41(4):39-43.

[9] Mao, Z. J., Mei, H., Xiao, Y.M., Huang, Y. X. (2020) Risk Assessment of Smart City Information Security Based on Bayesian Network. J. Modern Information. 40(5):19-26

[10] Xiao, Q. Z., Zhao, Z. N., Liu, L. C. (2021) Research on Construction Risk Management of Subway Project Based on Bayesian Network. J. Journal of Xinyang Normal University (Natural Science Edition). 34(1):138-144.