

Gray Relation Analysis of Human-caused Accidents in the Oil Industry

Guanlong Zhu

School of Economics and Management, Southwest Petroleum University, Sichuan, China

Abstract: Aiming at the characteristics of petroleum production accidents, such as high potential hazards, large economic losses and wide range of influence, in order to better formulate the accident risk management policy, it is necessary to have a deeper understanding of the reasons for the occurrence of accidents. By combing the accident investigation reports of the petroleum industry in recent years, we can effectively reduce the possibility of accidents by analyzing the direct and indirect causes of human-caused accidents based on the gray relation system from the human-caused aspect, identifying the main influencing factors and taking targeted preventive measures.

Keywords: Oil Industry; Human-Caused Accidents; Gray Relation Analysis.

1. Introduction

Oil is one of the world's most important sources of energy, and the oil industry is usually an important economic pillar of a country or region. However, oil production involves geological exploration, drilling, oil extraction, refining and other technical aspects, and its operating environment is complex, with high risks, such as fire, explosion and leakage. Accidents occurring in the oil production process may lead to property losses, casualties, and even trigger social unrest, seriously affecting the process of economic development. On November 13, 2005, an explosion occurred in the nitrobenzene distillation tower of Jilin Petrochemical Company's Double Benzene Plant, resulting in 8 deaths and 60 injuries, and triggering a water pollution incident in the Songhua River, which resulted in a severe impact [1]; from July 16, 2010, to 2017 August 17, 2010, Dalian Petrochemical Company of CNPC occurred a cumulative total of four large accidents, in addition to serious damage to the company's image, but also caused serious casualties, economic losses, and a far-reaching impact on the local environment and public safety.

In recent years, affected by the new crown epidemic, the production and operational efficiency of society has declined compared to before, also in the petroleum industry. In the early stages of the epidemic, strict closure measures were imposed in some areas, resulting in restrictions or suspension of operations at oil extraction and processing facilities. For example, in February 2020, Sinopec, China's largest oil producer, announced that it was suspending production at some of its refineries, but the oil industry still experienced a number of safety accidents during the 2020-2022 period, and human factors accounted for a fairly high percentage of the direct causes of these accidents. Currently, there are fewer studies on human unsafe behaviors in the production process of the petroleum industry, while systematic human factors engineering analysis is even rarer. Therefore, a systematic human factors engineering analysis of high-risk accidents in the petroleum industry is of great and practical significance for reducing the occurrence of high-risk accidents in petrochemical industry. Therefore, the causes in the accident investigation report are refined and analyzed to form the index system of gray relation analysis of human factors in

petroleum safety accidents, and then the key influencing factors of accidents are identified through the gray relation analysis method.

2. Gray Relation Analysis

2.1. Gray Relation Analysis Principle

Grey Relation Analysis (GRA) is a multi-factor statistical analysis method that uses gray correlation in a gray system to determine the strength of our items of interest by other factors [2]. Gray system means that the information in the system has incompleteness and non-uniqueness; gray correlation describes the relative changes between factors, and its numerical magnitude is sorted to get the gray correlation order, through which the degree of influence of each factor on the results is derived. Compared with traditional mathematical and statistical analysis methods, such as regression analysis, analysis of variance, principal component analysis, etc., gray correlation analysis is equally applicable to the number of samples and samples with or without patterns, and the calculation is small, and the results of the analysis generally coincide with the qualitative analysis.

2.2. Gray Relation Analysis Steps

Step 1: Determination of reference sequence:

$$X_0 = [X_0(1), X_0(2), \dots, X_0(n)]$$

Step 2: Determination of comparison sequence:

$$X_i = [X_i(1), X_i(2), \dots, X_i(n)], i = 1, 2, \dots, m$$

Step 3: To carry out the dimensionless processing, we got main methods: initialization, averaging, intervalization, etc., here the initialization is used to obtain:

$$X'_i = X_i / X_i(1), i = 0, 1, 2, \dots, m$$

Step 4: Find the sequence of differences, the maximum difference and the minimum difference. The difference sequence:

$$\Delta_i(k) = |X'_0(k) - X'_i(k)|, k = 1, 2, \dots, m$$

The maximum difference:

$$\Delta_i(\max) = \max_i \max_k |X'_0(k) - X'_i(k)|$$

The minimum difference:

$$\Delta_i(\min) = \min_i \min_k |X'_0(k) - X'_i(k)|$$

Step 5: Find the relation coefficient:

$$\xi_i(k) = \frac{\min_i \min_k |X'_0(k) - X'_i(k)| + K \max_i \max_k |X'_0(k) - X'_i(k)|}{|X_0(k) - X_i(k)| + K \max_i \max_k |X'_0(k) - X'_i(k)|}$$

K is the resolution factor, which generally takes the value of 0.5.

Step 6: Find the degree of relation. Since the relation coefficients only indicate the closeness of the relationship between the comparison series and the reference series at each time, which is not convenient for comparison, the data are centralized and the average value of each reference series is obtained as its correlation degree for comparison. The larger the correlation coefficient, the closer the relationship between the group of factors and the reference series, and the ranking obtained from the correlation coefficient is the gray correlation order.

$$\gamma_i = \frac{1}{N} \sum_{k=1}^N \xi_i(k), k = 1, 2, \dots, m$$

3. Gray Relation Analysis of Human-caused Accidents

The occurrence of accidents usually has a certain degree of chance, each accident is caused by one or several people's unsafe behavior in time or space at the same time, while causing accidents of human factors with difficult to capture and irreversible characteristics, which makes it difficult to analyze the relationship between the mutual influence of factors. However, according to the basic procedure of statistical analysis of accidents [3]: statistical investigation of accident data, processing and collation, comprehensive analysis, through the analysis of the accident investigation report can be found that human factors show a certain degree of repeatability, and there is a regularity to be followed in the statistical analysis of the results of the accident.

In order to ensure the authenticity and authority of the data source, this paper studies the safety production accident investigation reports published on the official website of the Ministry of Emergency Management for the years 2020-2022 in 31 provinces, autonomous regions, and municipalities directly under the central government (excluding Hong Kong, Macao, and Taiwan) of China, and from them, 27 safety production accident investigation reports in the petroleum

industry are selected as samples to be analyzed. Since gray correlation analysis is applicable to the number of sample sizes and the presence or absence of regularity, and the prediction accuracy of uncertain systems with small sample data and little information in the short and medium term is high, the gray system theory is used to analyze the degree of mutual influence between human factors and the key factors leading to accidents, and to explore the internal laws between human factors.

According to the safety system theory, the accident system involves four basic elements, usually called "4M" elements, namely: human unsafe behavior (Men), the state of disturbance of the object (Machinery), the adverse effects of the environment (Medium), the lack of management (Management) [4]. Among them, human unsafe behavior includes human psychological and physiological factors and human quality (operation level, safety awareness, cultural level, work responsibility, etc.); the uneasy state of the object contains the factors of machinery and equipment (defective devices, abnormal operation of equipment, operating tools do not meet the safety requirements, etc.); the adverse effects of the environment, including the conditions of the production and working environment (noise, vibration, temperature, lighting, etc., these factors will affect the operator's human body functions. all affect the operator's human body functions, so that the operator incorrectly accepts the information and produces incorrect operation, causing accidents; there are hidden safety hazards in the environment); the lack of management contains risk identification and control, safety education and training, and the implementation of the responsibility for production and safety (the management's failure to arrange the work, the lack of safety management rules and regulations, etc.). The petrochemical industry is a complex human-machine-environment system, and there are various uncertainties in the production process. Starting from this, the causal factors are divided into five categories by analyzing 27 accident investigation reports.

After carefully reviewing the original 27 accident investigation reports collected in the official website of relevant emergency management departments, the direct causes, indirect causes and the key words involving the four basic elements of safety system theory in the determination of responsibility for the accident are labeled and extracted and summarized, and the results of the collation statistics are shown in Table 1.

Table 1. Causal factors of safety accidents in Chinese petroleum enterprises

Time	Number of accidents	Quality of employees	Equipment status	Environmental impact	Implementation of production responsibility	Security education factor
2020	7	5	1	2	4	3
2021	12	7	5	3	9	3
2022	8	7	2	3	4	8

The number of accidents as a reference sequence, denoted as X0; the quality of employees, the state of equipment, environmental impacts, the implementation of production responsibility and safety education factors as a comparison sequence, denoted as X1, X2, X3, X4, X5. The results after the dimensionless processing of Table 1 are:

$$X'_0=(1,1.714,1.143), X'_1=(1,1.4,1.4), X'_2=(1.5,2),$$

$$X'_3=(1,1.5,1.5), X'_4=(1,2.25,1), X'_5=(1,1,2.667).$$

The sequence of differences is sought as:

$$\Delta_1=(0,0.314,0.257), \Delta_2=(0,3.286,0.857), \Delta_3=(0,0.214,0.357),$$

$$\Delta_4=(0,0.536,0.143), \Delta_5=(0,0.714,1.524).$$

Therefore, the maximum difference $\Delta(\max)=3.286$ and the minimum difference $\Delta(\min)=0$.

Taking K=0.5, the correlation coefficient is calculated:

$$\xi_1=(1,0.839,0.865), \xi_2=(1,0.333,0.657), \xi_3=(1,0.885,0.821),$$

$$\xi_4=(1,0.754,0.92), \xi_5=(1,0.697,0.519)$$

Calculated correlations are $\gamma_1=0.901, \gamma_2=0.663, \gamma_3=0.902, \gamma_4=0.891, \gamma_5=0.739$.

The gray correlation order is $\gamma_3 > \gamma_1 > \gamma_4 > \gamma_5 > \gamma_2$. i.e., the adverse effect of the environment > employee quality >

implementation of the responsibility of safety production> safety production education and training>state of machinery and equipment. Since the correlation reflects the degree of influence of each factor on the results, it can be seen that in the last three years of production activities in the oil industry, the environmental factors, the quality of employees and the implementation of corporate responsibility for production safety are the main factors causing production safety accidents, and the other factors are, in order, the state of production safety education and training, and the state of the machinery and equipment operated during production.

4. Countermeasures and Recommendations

The losses and consequences caused by production safety accidents are irreversible, but the enterprises concerned can prevent the accidents from occurring through certain means and measures beforehand, so as to avoid unnecessary losses. Through the analysis of the accident investigation reports available in these three years, when organizing and carrying out production activities, petroleum enterprises should pay attention to the existence of safety hazards in the production and operation environment, the quality of employees and the implementation of production responsibility. At the same time, in the process of reviewing different accident investigation reports, it can be found that there is a certain difference in the focus of the content of the investigation reports, which may cause the public to question the transparency of the accident reports.

4.1. Establishment of Sound Inspection Mechanisms for Production Sites

The production of petroleum enterprises adopts unique machinery and equipment, and when necessary, they will carry out production operations in special production environments, where lighting, temperature, noise and toxic materials or substances that may be used in production will have different impacts on the human body, so that the operators will receive incorrect information and improper operation, which will lead to production accidents. Therefore, enterprises should establish a mature inspection mechanism, organize regular safety inspections and random inspections of production sites from time to time to eliminate possible safety hazards and ensure that employees can work in a safe and comfortable environment, which not only avoids safety accidents, but also improves their productivity and creates long-term value for the enterprise.

4.2. Construction of Employee Education and Training System

Education and training of employees should not be limited to the daily pre-shift safety training, but also involves the staff's operating skills, cultural level, sense of responsibility, etc., so there is a need to have a comprehensive training system to support. The production process of the petroleum industry is relatively special and complex, and has high requirements for the craftsmanship of production personnel, so enterprises should be based on different positions, types of work, combined with national laws and regulations to develop the introduction of safe operation system, the level of operation of the staff should be strictly controlled, to avoid accidents caused by improper operation in the production process, to ensure that the production of safe and secure rules

and regulations to follow. It is worth noting that after the training, we should follow up the training effect in time, evaluate the training results, and measure whether the training has a positive impact on the production activities of the enterprise after a period of time. At the same time, some employees may be limited by the level of education, some harmful production materials do not have enough awareness and vigilance, which also needs to attract the attention of the enterprise to ensure that each operator is clearly aware of the potential hazards in production. In addition, managers should pay attention to the physiological and psychological qualities of production personnel, to avoid the phenomenon of sick people insisting on working or having psychological problems and still carrying out production operations.

4.3. Improvement of the Management System

Enterprises should optimize the existing organizational structure, to achieve the unity of professional division of labor and the coordination of various departments, to ensure that each department can freely exercise their independent rights at the same time, and clearly define their respective responsibilities, to avoid the occurrence of management errors and confusion. In addition, the establishment of a safety monitoring mechanism, and will be included in the management of the responsibility, when the responsibility is clearly implemented in a position, the supervision effect can better play its role, and in the event of accidents can be traced back to the corresponding personnel. This is also to better identify the possible risks in the production process of the petroleum industry, to ensure that operators in a safe working environment to operate the machinery and equipment without hidden dangers, so as to achieve intrinsic safety.

4.4. Establishment of Standards for Analyzing Reports on Oil Safety Accidents

In the process of reviewing the accident investigation reports, it can be found that, in addition to the accidents with investigation reports published on the official websites of the emergency management departments, there are many accidents reported by the media, as well as many smaller accidents that are not publicly reported, and the number of accidents that actually occurred may be different due to differences in the transparency of the investigation reports and the collection of data. Moreover, the content of accident investigation reports published on official websites shows that the analytical focus of general safety accidents and major safety accidents is not the same. The reason for this phenomenon is that the investigation and analysis of the causes of major safety accidents are mainly done by experts from the State Safety Supervision Bureau, while general safety accidents are often done by the security departments of localities or enterprises. This is also a problem that often occurs in the analysis and investigation of domestic safety accidents. Therefore, there is an urgent need to establish standards for safety accident analysis reports in the petroleum industry in order to standardize the investigation and analysis of safety accidents within the industry.

5. Conclusion

This thesis synthesizes the information sources published on the official websites of China's emergency management ministries, and statistically analyzes the collated data. On the basis of statistical analysis of production accidents in the

petroleum industry, human factors engineering analysis was conducted to identify human causes, physical causes and environmental causes, and various measures to reduce human errors were proposed to provide reference for reducing the occurrence of high-risk accidents in the process of petroleum production. At the same time, in the process of searching for each accident investigation report, we found that its content focuses on different aspects, which illustrates the problems in the investigation of safety accidents and the necessity of standardization of investigation reports, and points out the direction for future research.

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