ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0097

# Research on Fire/Explosion Investigative Reports based on Content Analysis Method

Yudong Liang, Su Xu, Siyuan Liu, Liangjun Chen, Linhan Shen

Southwest Jiaotong University Chengdu 611756, China

## Abstract

**The content analysis method is used to study the root causes and precursors of industrial explosions and fire. Case studies of industrial explosions and fire will be used to determine common causes and accident recommendations. Most of the existing literature is the qualitative analysis of these cases; however, they only consider the root causes, not precursors. The texts of the investigative reports were analyzed to determine both of them. It is expected that this new approach to help investigators identify and transmit those common precursors of future incidents, and help facility leaders improve their prevention systems by implementing mitigating measures that would prevent events from occurring.**

## Keywords

**Content Analysis Method; Fire Explosions; Root Causes; Precursors.**

## 1. Introduction

In recent years, with the increasing demand for Industry and energy (especially fossil fuels). The plant contains a large number of flammable and dangerous hydrocarbon fuels and chemicals, resulting in increased hazards. As a convenient and efficient storage tool, oil tanks have been paid attention to. By analyzing the causes of fire and explosion related to external floating bodies, the research found that uncontrolled reaction, static electricity, fire safety system failure, and natural disasters increase the incidence of fire and explosion (Moshashaei, 2017). Human factors are also one of the main causes of fire and explosion. It contains a lot of uncertainty and greatly increases the potential risk of fire and explosion. Based on the model of petrochemical enterprise fire and explosion systems (HFACS - PEFE) which studies human error, it shows that violations, intelligible restrictions, equivalent supervision, and lack of safety culture are the main causes (Chen et al., 2019). There are a lot of safety management problems behind occupational accidents that need to be investigated. The classification regression tree (CART) was excavated for data mining inspection, and it was found that fire, explosion, and poisoning caused by material leakage and employees involved/involved in machinery are common reasons in the process of occupational production (Cheng & Wu, 2013). Root causes are the basic cause (or multiple causes) that managers can identify and fix using control. Then an effectual recommendation can eliminate (or significantly reduce) the possibility of the accident occurring again (Rooney & Heuvel, 2004).Identifying the root cause is the key to preventing accidents because there can be many reasons for the accident to happen, but the root cause is the biggest hole in the last barrier between the accident and the non-occurrence. If there is the same point of the root cause, it is equivalent to finding the same point of most accidents, and then can effectively avoid their recurrence. But accidents are always different across industries, so when narrowing down to accidents like industrial fires and explosions, generalizing about the root causes of their occurrence may be helpful in this particular field.Safety culture may be an important part of the root causes of industrial fires and explosions. Safety culture is a set of universal metrics, beliefs, and values about safety possessed by an organization (Mohammadi & Mehdi, 2020). Fu (2013 & 2016) concluded an accident causation

ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0097

model which considered the safety culture as the root cause of accidents. As shown in Figure 1, safety culture relates to route 4 and is relative to the most likely route to cause fire and explosion(5.31%). This study shows that safety culture is the root cause of fire and explosion accidents in petrochemical enterprises (Cheng et al., 2019). A study of coal mine accidents identified safety culture as an organizational factor in safety cases and the root cause of accidents (Zhang et al., 2020). Bhattacharjee, Dash, and Paul (2020) also identified some organizational factors as root causes, such as poor security culture, lack of hazard/threat perception, lack of risk assessment culture, etc., which have been dormant in organizations for a long time. In other words, the root cause of the incident may have occurred long before the incident and may be far removed from the scene of the incident (Mohammadi & Mehdi, 2020).Through a review of previous relevant literature, most researches analyzed root causes based on Heinrich's domino theory and set up related models. Abdelhamid, Tariq S, and John G Everett proposed an Accident Root Cause Tracking Model (ARCTM) adapted to the needs of the construction industry The HFACS model of Chen et al (2020) corresponds to Reason's Swiss cheese model and examines the role of human factors in the petrochemical industry. (2019) There is also a study investigating the root causes of coal dust explosions in India, mainly using the ACT accident causal tree and the Swiss cheese model (Bhattacharjee & Paul, 2020). The advantage of this is that the analysis results are very detailed and reliable, but the disadvantage is that it cannot provide general, statistical conclusions on the prevention of industrial fires and explosions.One of the conclusions of accident causality theory is that accidents are caused by system failures and not by a single factor such as unsafe conditions (Mohammadi & Mehdi, 2020). Therefore, this study attempts to conduct some systematic analysis of industrial fires and explosions based on previous theories and through content analysis, to sort out the variables involved in organizational factors such as safety culture and other root causes, and find them related to SIF, precursors and other variables are linked to obtain relatively effective prevention programs.

## 2. Content Analysis Method

Content analysis is the study of documents and communication artifacts, which might be texts of various formats, pictures, audio, or video. Social scientists use content analysis to examine patterns in communication in a replicable and systematic manner. The practice and philosophy of content analysis vary from discipline to discipline. They all rely on the systematic reading or observation of texts or artifacts that are assigned tags (sometimes called codes) to indicate the presence of interesting and meaningful pieces of content.Content analysis can be understood as a broad technology group, and effective researchers choose the technology that can help them answer substantive questions the most. In other words, according to Klaus Krippendorff, six problems must be solved in each content analysis: Which data are analyzed? How are the data defined? From what population is data drawn? What is the relevant context? What are the boundaries of the analysis? What is to be measured? (Krippendorff, K., 2004) When studying content analysis, American communication scholar Bernard Berelson pointed out: “Content analysis is a research method for objective, systematic and quantitative description of communication content. (Berelson, 1952)” Content analysis generally involves selection, In the three stages of classification and statistics, the following three methods can be adopted: (1) Record or observe the content of a certain media in a certain period; (2) Analyze and analyze the content reported by the same media in different period comparison; (3) Analyze and compare the content, methods, and methods reported by different media in the same period on the same event, or the same subject to find out the similarities and differences (Liu & Wang, 1993).In order to study the root causes of industrial fires and explosions and the relevance of precursor events, some investigation reports have been collected and the variables needed for the research have also been selected (These two parts will be introduced in detail in the next section). Content analysis shows that content analysts can consult academic literature and applied research at the same time, and use theory as a guide as much as possible. Thus, those literature are the basic sources of variables in the research of industrial fires and explosions. In order to classify a series of root causes and precursor events from the collected cases, a coding scheme with a coding form had been already made (see

ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0097

Appendix A). This idea is what Neuendorf (2017) mentioned in the operationalization section of Chapter 2 of Content Analysis, "For content analysis, this means the construction of a coding scheme, which is either a set of dictionaries (for text analysis) or a set of measures in a codebook". The coding form will be filled with the accident cases found in official reports, and the root causes and precursors in that form will exist as research variables. According to the requirements of content analysis, the coding scheme produced can help understand the meaning of the coding form, so as to make the completion of the form more convenient. After finishing the production of the coding form, the coding form composed of variables selected in the literature needs to be tested for reliability, which is a very important part of content analysis. In the sixth chapter of content analysis, reliability is defined as "the extent to which a measuring procedure yields the same results on repeated trials." (Neuendorf, 2017) Through the method provided in the chapter, the reliability of these variables will be tested by multiple coders to verify the consistency of these variables. That is to say, whether these variables can be used to detect accident cases.

## 3. Cases Evaluation

According to the FPSO Cidade de São Mateus gas explosion (Vinnem, 2018), the report compares and analyzes three explosion accidents. The three accidents are the Macondo accident, the Heimdal gas leak, and the Cidade de São Mateus gas explosion. In this report, the author listed the root causes of the three accidents separately and classified the main root causes of the FPSO Cidade de São Mateus gas explosion. Inspired by this report, the investigation and selection of the root causes of industrial fires or explosions can come from related reports and literature, and these root causes can be used as the main variables to be studied.A total of 9 variables were defined, and these 9 variables can be divided into two categories. These two categories are set as root causes and precursors, and they are also objects that need to be studied. Among the 9 variables that have been defined, 4 can be classified as root causes. These four variables are human factors, job factors, programme factors, and compliance factors (Amyotte, 2002). The remaining five variables can be included in the precursor. They are unexpected maintenance, process instability, manual handling, unexpected changes, and emergency shutdown procedures (Krause, 2012).

In the root cause, the 4 variables are defined as follows: (1) Human factors are the psychological, behavioral, and other attributes and characteristics of an individual or group of individuals whose effects on work behavior may affect health and safety. Behaviors such as personnel lack of work experience, and psychological stress caused by environmental conditions (fear or other) can all be considered human factors. (2) Work factors refer to factors such as work patterns, workplace culture, resources, leadership, and supervision that affect safety, including behaviors such as lack of proper orientation and training for employees, poor leadership in the assignment of responsibilities, and lack of supervision. (3) Programme factors refer to problems existing in program management, such as managers failing to take safety issues seriously, failing to conduct program evaluation and review, and insufficient review. (4) Compliance factors represent the degree to which an industry adheres to standards, norms, or rules. Poor correlation between conduct and safety production policies and work that does not meet legislative standards are considered as part of the compliance factor.

The five variables in the precursor should be defined as follows: (1) Unexpected maintenance should be defined as any maintenance task that occurs unexpectedly. For example, workers perform maintenance operations outside of equipment maintenance cycles, resulting in accidents. (2) Process instability is defined as any instability in the process leading to an accident. This means that in the whole process, the equipment itself has an unstable risk factor. For example, the design of this equipment could very well cause it to malfunction, but workers did not notice it in the process or did not fix it, eventually leading to an accident. (3) For manual handling, should be defined as the actions of pushing, pulling, lifting, and repetitive tasks such as typing, assembling, and cleaning that occur in daily operations that ultimately lead to accidents. (4) Unexpected changes can be considered external factors such as natural disasters (weather, floods, etc.), but also sudden damage to machinery prior to the accident. (5) An emergency shutdown procedure is when a factory implements an

ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0097

emergency shutdown and workers are unaware that the procedure has been implemented and they are still working, resulting in an accident. Such emergency shutdowns include emergency shutdowns of the entire plant; emergency shutdowns of one or some units within the plant; process shutdowns within the plants; and planned emergency shutdowns of processing units. Both human factor and job factor have something related to “lack of training”. In order to distinguish these two variables, human factor is defined as when an employee does not consciously participate in the required training. This is a job factor when a company does not provide adequate training to its employees. For the precursors, both manual handling and Process instability showed good reliability. This may be related to their own definitions that are easier to understand, and it is easier for different coders to reach a consensus on these two variables.

For each variable, what conditions can be classified into the variable will be reflected in the codebook (see appendix A). For example, lack of work experience, insufficient education and training, and lack of safety knowledge can be classified as human factors; while factors such as incorrect packaging and storage and insufficient leadership in the allocation of responsibilities should be considered as job factors. The rest will be explained in the codebook (see appendix A).

Studying the influencing factors and precursor events of industrial fire and explosion accidents has theoretical and practical significance for preventing industrial fire or explosion accidents. The factors involved in industrial fires or explosions are complex and are generally caused by multiple factors. These selected root causes and precursors are all from those mentioned in other literature. It is believed that these variables can represent most of the causes of industrial fire or explosion after passing the follow-up reliability test. Each subsequent accident investigation report will be analyzed through these variables to find the correlation between the root causes and the precursor, which is also the reason and significance of the selection of these variables.

## 4. Spearman's rho and Pearson R

Spearman's rho is called Spearman rank correlation coefficient which is used to understand the strength of the relationship between two variables. The variables here do not refer to the “Variables” as mentioned above and they describe cases coding result by different coders. The Spearman's rho can be used in the following scenarios: 1. want to know the relationship between two variables, 2. variables are continuous with outliers or ordinal, 3. only have two variables (Maritz, J.S. 1981). This reliability test fits the second point.Pearson R is also called Pearson correlation coefficient and it is similar to Spearman's rho. It is also used to measure the correlation between two variables. The result of Pearson R and Spearman's rho is used as a standard for double reliability testing.For correlation coefficient values, some specific criteria may be arbitrary or unreasonable, because different backgrounds and purposes require different values (Cohen, J., 1988). For this project, a final result greater than 80% is considered credible.

## 5. Analysis Method

In order to prove whether there is a relationship between fire and explosion, the chi-square independence test was considered best for the research. This is a hypothesis test that can judge whether two factors are interrelated or independent according to frequency data (Bluman, 2014). Chi-square statistics is a nonparametric (non distributed) tool. Unlike many parameter statistics, it does not require equal variance between study groups or data homo variance and can provide a lot of information about factors in the study. These rich details are convenient for a better understanding of the research results (Zimmerman & Deborah, 2015). This is exactly the test method in which the data characteristics presented by our coding scheme are consistent.There are two factors: the root causes and the precursors of fire and explosion. In order to test whether there was a relationship between them, the frequencies of root causes were counted when precursors occur and no precursors occur. Since there are multiple variables in the root cause, it is applicable to the chi-square independence test to verify whether the classification of two or more factors is related or independent of each other.

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After counting the frequency of each occurrence, the formula of the chi-square independence test can be substituted to obtain the intuitive chi-square value and standard value (it is the corresponding value in the critical state, so it can determine whether the factors are related), which is simple and fast. This is also the reason why choose chi-square independence test was chosen.Ensure that the two are related to the critical value (α ) needs to reach more than 95%. Since the chi-square independent test calculates the chi-square value rather than the percentage, converting the value corresponding to the critical value under the degree of freedom for comparison should be completed. Therefore, it is necessary to calculate the degree of freedom with the number of rows and columns according to the formula and then refer to the table to match the degree of freedom to obtain the value when α =95%. Finally, substitute the occurrence times of the root cause with or without precursors to obtain the chi-square value. Compare the two. If the chi-square value is greater than the critical value after conversion, it indicates that the two factors are interrelated.

## 6. Result

After the first inter-coder reliability test, all of Spearman's rho of the variables was greater than 0.8, which is shown in figure 5.1 below. There were six variables (Human factors, Job factors, Programme factors, Compliance factors, Process instability, and Manual handling) whose Pearson R was greater than 0.8 and two variables whose Pearson R was lower than 0.8. This might suggest that Pearson's R is more efficient than Spearman's Rho in representing monotonic nonlinear relationships (Van Den Heuvel, & Zhan, 2022). Only one variable's Spearman and Pearson values were close to 1.

| | Root Causes | | | | Precursors | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Human factors | Job factors | Programme factors | Compliance factors | Unexpected Maintenance | Process Instability | Manual Handling | Unexpected Changes | Emergency Shutdown Procedures |
| Pearson's R | 0.92934 | 0.96422 | 0.83607 | 0.94577 | 0.57735 | 0.92593 | 0.9037 | 0.60246 | 1 |
| Spearman' Rho | 0.99844 | 0.99733 | 0.99444 | 0.998 | 0.99867 | 0.99911 | 0.99933 | 0.99778 | 1 |

**Figure 1.** Result of first inter-coder reliability test

After the second inter-coder reliability test, all the variables were reliable. Then a data set of all of the fire reports was made and is shown in figure 2 below.

| Accident | Accident Occured On | Investigation ID | Root Causes (Count the number of factors in each cases) | | | | Precursors | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Huaman Factors | Job Factors | Programme Factors | Compliance Factors | Unexpected Maintenance | Process Instability | Manual Handling | Unexpecte d Changes | Emergency Shutdown Procedures |
| Third Coast Industries Petroleum Products Facility Fire | 03/06/2003 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Herrig Brothers Farm Propane Tank Explosion | 06/23/199 | 2 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| Isotec/Sigma Aldrich Nitric Oxide Explosion | 0921/2003 | 3 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 |
| . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . | . . . |
| Evergreen Packaging Paper Mill-Fire During Hot Work | 09/21/2020 | 58 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| Optima Belle LLC Explosion and Fire | 12/08/2020 | 59 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bio Lab Chemical Release | 09/14/2020 | 60 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 66 | 103 | 48 | 42 | | | | | | |

**Figure 2.** Data set of 60 fire reports

Volume 8 Issue 8, 2022
DOI: 10.6919/ICJE.202208_8(8).0097

The actual chi-square value is 64.871 > 7.815.

In addition, the data in the table were sorted and classified to count the root causes and the number of their specific variables in the case of precursors and the case of no precursors. The number of variables of five root causes was made into a percentage, which reflects the frequency of variables in fire and explosion cases and which causes are more common in cases.

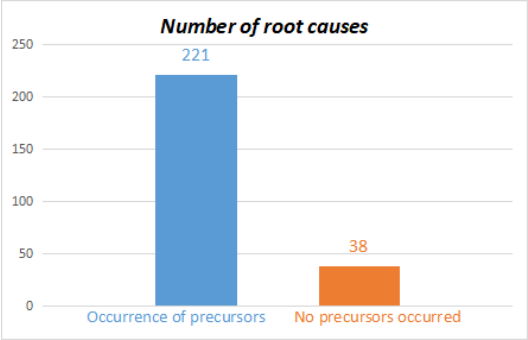


**Figure 3.** Number of root causes

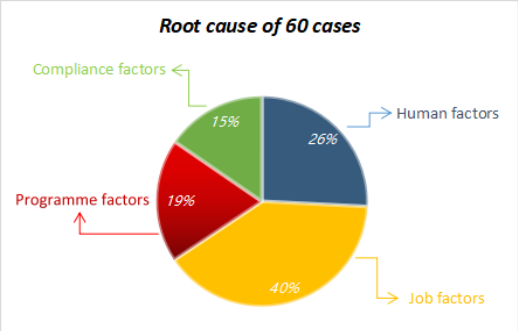


**Figure 4.** Root causes of 60 cases

## 7. Discussion

After chi-square testing, the result is 64.871. In the previous description, the critical value needed is greater than 95%, and after calculation, the degree of freedom is 3. So the value is 7.815, which means if the chi-square testing result is greater than 7.815. It is believed that the precursors and root causes are interrelated, and the value seems a lot more than 7.815. This shows that there is a strong correlation between precursors and root causes. There is only a correlation that can be proved, but not what kind of correlation, because the chi-square test cannot prove it. There are two correlations which are positive correlation and negative correlation. As for whether it is a linear correlation, our study does not care about this point. As long as to whether it is a positive correlation or a negative correlation was proved, the attention to another type of variable can increase or decrease through changes in one type of variable, because what is studied is the type of the whole variable rather than the effect of a single variable on other variables. One of the conclusions of accident causality theory is that accidents are caused by system failures composed of a combination of variables, rather than by a single cause or factor such as the job factor (Mohammadi & Tavakolan, 2020). Therefore, for the industrial fire or explosion, each accident is not caused by a single factor, but by many obvious or potential factors. A positive correlation means that when one variable increases, the other variable also increases. For our project, if there are increases in the precursors, then the root causes will also increase. While root causes are usually initiating causes of either a condition or a causal chain that leads to an outcome or effect of interest. For our project, root causes are the actual causes of fire or explosion accidents. That means that if the precursors were, the root causes will also occur with a

ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0097

high probability, then the industry can prevent the root causes based on the precursors, thereby reducing the occurrence of fire and explosion accidents.

Under normal circumstances, our group generally thinks that the relationship that exists between these two variables is a positive correlation. Because in all the cases collected, there is not a single case without precursors or root causes. Since there is no situation where there is only a single type of variable, it means that there is a high probability that the two variables are not negatively correlated.

If there is a direct negative correlation between precursors and root causes, it means that one of them increases and the other one decreases. Then in industrial production, a method must be taken to make the precursors appear in large numbers because once the precursors appear in large numbers, the root causes will be reduced, thereby reducing the occurrence of accidents. But predictors are some problematic variables, such as Unexpected changes. This variable defines unexpected changes, such as a natural disaster (weather, floods, etc.) and the mechanical failure that precedes an accident. As far as this one variable is concerned, it makes negative impacts on any industry. It cannot be kept increasing the number of such precursors because of its negative effects. Even if the two types of variables are negatively correlated, there is no way to reduce the occurrence of root causes by increasing the number of predictors.

## 8. Conclusion

The content analysis guide provides the methodology, theory, and practice for this research. Statistics and validation of fire and explosion root causes and precursors variables are the top priorities of this study. The study mainly focuses on the content of industrial fire cases. Then, provide references for industrial fires and explosions, and improve the safety environment of workers and industrial property in different directions. The content analysis method is based on a large number of documents and integrates the reports to prepare our coding scheme. This research collected 60 case reports are the results of the reports on fires and explosions in recent 20 years. The coding scheme has been discussed and modified by the group members many times, and its reliability has been further determined through double testing, Ensuring that the correlation coefficient of each variable of the coding scheme is higher than 0.8, which not only shows the reliability of the variables involved in the definition of the case but also shows that the data of the root causes and precursors involved in the case are scientifically based and can be used. Ensured the reliability of the data, then counted the number of root causes in the coding scheme with and without precursors, substituted them into the formula for the chi-square independence test, and compared the actual value with the chi-square critical value. When got that the actual value is greater than the critical value, and conclude that the precursor of fire and explosion was related to the root cause, which was an exciting discovery, It means that the solution of accident analysis cases is not limited to the suggestion of root cause.

The final review shows that job factors account for the largest proportion of root causes in industrial fire and explosion cases and that there are far more cases of precursors than non-occurrences. The main finding of this research is that root causes and precursors are linearly correlated, which is definitely not a natural relationship. It can be explained that the correlation between root causes and precursors helps professionals to focus not only on root causes but also on precursors when evaluating cases, which is reflected in previous investigation reports. The emergence of precursors can better summarize the accident and facilitate others to better understand the case. At the same time, as for prevention, more preventive measures from relevant industries and companies are to pay attention to the root causes of fire and explosion. Precursors can be used as the new standard rules of the risk assessment report, which can also enrich the implementation of preventive measures and effectively protect people's life and safety.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202208_8(8).0097

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