Analysis on Dangerous Source of Large Safety Accident in Storage Tank Area

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Abstract. The difference between a large safety accident and a general accident is that the consequences of a large safety accident are particularly serious. To study the tank area which factors directly or indirectly lead to the occurrence of large-sized safety accidents. According to the three kinds of hazard source theory and the consequence cause analysis of the super safety accident, this paper analyzes the dangerous source of the super safety accident in the tank area from four aspects, such as energy source, large-sized safety accident reason, management missing, environmental impact. Based on the analysis of three kinds of hazard sources and environmental analysis to derive the main risk factors and the AHP evaluation model is established, and after rigorous and scientific calculation, the weights of the related factors in four kinds of risk factors and each type of risk factors are obtained. The result of analytic hierarchy process shows that management reasons is the most important one, and then the environmental factors and the direct cause and Energy source. It should be noted that although the direct cause is relatively low overall importance, the direct cause of Failure of emergency measures and Failure of prevention and control facilities in greater weight.

1. Introduction
In recent years, at home and abroad, the extremely severe safety accidents have occurred, Huangdao 8.12 Fire accident in 1989, Buncefield accident in 2005, Dalian 7.16 accident in 2010, Tianjin 8.12 accident in 2015 and so on, each accident caused great loss and serious social influence (1, 2, 3). Although there are few cases of large-size safety incidents in the storage tank area, they will always occur at intervals from the year. Each case has its contingency and inevitability, which hides the law of the accident. To study the risk factors of large-sized safety accidents, and eliminate the contingency of large safety accidents fundamentally.

2. Risk factor analysis
The storage tank area does not involve the processing and production of energy, and its main function is to store and transport, very few man-made chemical reaction operations. Storage and transshipment are mainly related to various types of storage tanks and pipelines, early warning facilities and contingency measures.
The types of accidents that can occur in storage tank areas are leaks and poisoning accidents which are relatively slow in evolution and relatively stable energy. The most important factor in the development of leakage accident and poisoning accident is the accumulation of leakage quantity (4, 5). Another kind is fire and explosion accident, the fire and explosion accident is difficult to control, develops rapidly, and extremely easily develops into the big security accident (6, 7).

Energy substances, reasons that cause the failure of the bundle energy facilities, management factors are the main analysis of the risk source content respectively from first to the third kind of hazard source(8), but did not show the environmental factors, which affect the consequence of accident.

Energy source mainly includes the storage tank area where the capacity of the stored dangerous material reaches the standard of the major hazard source, is the source of the great safety accident (9, 10), vapor produced by a dangerous substance reaching a burning, explosive concentration (11), The poison that led to casualties. Lightning that can ignite the store (12), various forms of ignition sources exists in storage tank area (13)

Direct cause mainly includes the failure of storage transport facilities, Personnel error in process operation (14, 15), Safe liquid level, flow rate and other prevention and control facilities failure or prevention design defects (16), the fire dike which prevent leakage, the accident pool which guide and keep leaking storage (17), failure of emergency measures such as firefighting facilities (7).

Management reasons mainly includes staff skills training, staff Life Management, detection of storage devices, development of process operating standards and other rules and regulations, Installation of control equipment, development and periodic inspection of emergency response system (18, 19, 20).

Environmental analysis mainly from two aspects, which are environmental sensitivity and environmental impact on the consequences. The environmental sensitivity discussed in this paper includes natural ecological environment and social environment. Sensitivity indicates that environmental systems are sensitive to the disturbance of nature and human activities and can reflect the likelihood of environmental imbalances and problems. The impact of the environment on the accident is mainly the promotion of the consequences. Mainly includes the following cover pages. The storage tank area close to the residents living quarters, the surrounding residents are vulnerable to the impact of the accident (21). Port storage tank area for the convenience of water transport, mostly built next to the waterway. When the accident occurred, the water environment will be destroyed, aquatic species will be difficult to survive, and port loading and unloading operations will be difficult to carry out (14). The location of the storage tank should be avoided in the relatively high terrain, because in the event of an accident, the low-lying area must be affected (22). The low-lying places are prone to accumulate leaked storage vapors and poisonous gases. There should not be too much vegetation in the tank area.

3. AHP evaluation of large-sized safety accidents

Through analytic hierarchy process, we can draw the weight of each kind of hazard source and the weight of each subordinate factor. Finally, according to the weights of the four kinds of hazard sources and the weights of the factors in each type of hazard source, the weights of each factor relative to the large safety accident are obtained. Based on the analysis of risk factors above, the specific models and contents of the evaluation are shown in Table 1 below (23).
Table 1. Analytic Hierarchy Process Evaluation table

| Target Layer | Indicator layer | Factor layer |
|--------------|-----------------|--------------|
| Energy source| Major hazard sources | Vapor concentration of dangerous matter |
| | | Lightning |
| | | Fire |
| Direct cause| Personnel violation | Personnel Operation Error |
| Large safety accident in storage tank area| Failure of prevention and control facilities |
| Failure of emergency measures | Storage device Failure |
| Personnel operation procedures | Emergency system Design |
| Management reasons| Personnel skills Training |
| | Staff Life Management |
| | Company violation |
| | Close to the fairway |
| | Close to the living area |
| Environmental factors| High topography storage tank area |
| | Low-lying place |
| | Vegetation in the area |

To create a judgment matrix by consulting relevant literature, expert grading, and comprehensive consultation, according to the significance of the score and the different points represented in table 2, each layer element in table 1 is quantified, then the weight set is calculated, and the consistency ratio check the weight is effective.

Table 2. Signification of scales

| Proportion scale | Meaning |
|------------------|---------|
| 1                | Compared with the two elements, the former and the latter are equally important. |
| 3                | Compared with the two elements, the former is slightly more important than the other two elements. |
| 5                | Compared with the two elements, the former is significantly more important than the other two elements. |
| 7                | Compared with the two elements, the former is Highlight more important than the latter. |
| 9                | Compared with the two elements, the former is absolutely more important than the other two elements. |
| 2, 4, 6, 8       | Represents the intermediate value of the adjacent judgment |

Table 3. Random Consistency Reference Indicator table

| Order number n | 1   | 2   | 3   | 4   | 5   |
|----------------|-----|-----|-----|-----|-----|
| R.I.           | 0.58| 0.9 | 1.12|     |     |
The specific rating of four categories of hazard and the factors in each type of hazard are shown in table 4, table 5, table 6, table 7 and Table 8 (23, 24). Table 9 shows the order of weights for all elements in the four types of hazard sources.

**Table 4.** Four kinds of hazard source judgment matrix and weight distribution

| Energy source | Direct cause | Management reasons | Environmental factors |
|---------------|--------------|--------------------|-----------------------|
| Energy source | 1            | 1/2                | 1/6                   | 1/4                   |
| Direct cause  | 2            | 1                  | 1/5                   | 1/2                   |
| Management reasons | 6        | 5                  | 1                     | 3                     |
| Environmental factors | 4     | 2                  | 1/3                   | 1                     |

Maximum eigenvalue $\lambda_{max}$=4.0488, Weights is (0.0706,0.1223,0.5708,0.2352), consistency ratio CR=0.0180<0.1, satisfying consistency

**Table 5.** The energy source judgment matrix and weight distribution

| Major hazard sources | Vapor concentration of dangerous matter | Lightning | Fire |
|----------------------|-----------------------------------------|-----------|------|
| Major hazard sources | 1                                       | 2         | 1/4  |
| Vapor concentration of dangerous matter | 1/2                                   | 1         | 1/3  |
| Lightning           | 4                                       | 3         | 1/2  |
| Fire                | 5                                       | 4         | 1    |

Maximum eigenvalue $\lambda_{max}$=4.1389, Weights is (0.1128,0.0897,0.3075,0.4900), consistency ratio CR=0.0514<0.1, satisfying consistency

**Table 6.** The direct cause judgment matrix and weight distribution

| Personnel violation | Personnel Operation Error | Failure of prevention and control facilities | Failure of emergency measures | Storage device Failure |
|---------------------|---------------------------|-----------------------------------------------|--------------------------------|------------------------|
| Personnel violation | 1                         | 1/3                                           | 1/6                            | 1/8                    | 2                      |
| Personnel Operation Error | 3                     | 1                                             | 1/4                            | 1/5                    | 4                      |
| Failure of prevention and control facilities | 6                      | 4                                             | 1                              | 1/2                    | 5                      |
| Failure of emergency measures | 8                    | 5                                             | 2                              | 1                      | 8                      |
| Storage device Failure | 1/2                   | 1/4                                           | 1/5                            | 1/8                    | 1                      |

Maximum eigenvalue $\lambda_{max}$=5.1995, Weights is (0.0561,0.1214,0.3032,0.4768,0.0426), consistency ratio CR=0.0445<0.1, satisfying consistency
Table 7. The management reasons judgment matrix and weight distribution

| Personnel operation procedures | Emergency system Design | Personnel skills Training | Staff Life Management | Company violation |
|-------------------------------|-------------------------|--------------------------|-----------------------|-------------------|
| Personnel operation procedures | 1                       | 1/3                      | 1/6                   | 1/8               |
| Emergency system Design       | 3                       | 1                        | 1/4                   | 1/5               |
| Personnel skills Training     | 6                       | 4                        | 1                     | 1/2               |
| Staff Life Management         | 8                       | 5                        | 2                     | 1                 |
| Company violation             | 1/2                     | 1/4                      | 1/5                   | 1/8               |

Maximum eigenvalue $\lambda_{max} = 5.2307$, Weights is (0.1091, 0.3258, 0.0379, 0.0553, 0.4719), consistency ratio CR=0.0515<0.1, satisfying consistency.

Table 8. The environmental factors rating table

| Close to the fairway | Close to the living area | High topography storage tank area | Low-lying place | Vegetation in the area |
|----------------------|--------------------------|----------------------------------|-----------------|------------------------|
| Close to the fairway | 1                        | 1/5                              | 3               | 5                      |
| Close to the living area | 5                        | 1                                | 5               | 7                      |
| High topography storage tank area | 1/3                        | 1/5                              | 1               | 2                      |
| Low-lying place       | 1/5                      | 1/7                              | 1/2             | 1                      |
| Vegetation in the area | 2                        | 1/2                              | 5               | 1                      |

Maximum eigenvalue $\lambda_{max} = 5.1755$, Weights is (0.1522, 0.4633, 0.0671, 0.0407, 0.2768), consistency ratio CR=0.0301<0.1, satisfying consistency.

Table 9. Four kinds of risk factor weight ranking table

| Assessment of large-sized safety accidents in tank area | Energy source | Direct cause | Management reasons | Environmental factors | Factor weight | Weigh sort |
|-------------------------------------------------------|---------------|--------------|---------------------|-----------------------|---------------|------------|
| Major hazard sources                                  | 0.1128        | 0.1223       | 0.5708              | 0.2352                | 0.0080        | 16         |
| Vapor concentration of dangerous matter               | 0.0897        |              |                     |                       | 0.0063        | 18         |
| Lightning                                              | 0.3075        |              |                     |                       | 0.0217        | 11         |
| Fire                                                   | 0.490         |              |                     |                       | 0.0346        | 9          |
| Personnel violation                                    | 0.0561        |              |                     |                       | 0.0069        | 17         |
| Personnel Operation Error                              | 0.1213        |              |                     |                       | 0.0148        | 14         |
| Failure of prevention and control facilities           | 0.3031        |              |                     |                       | 0.0371        | 7          |
| Failure of emergency measures                          | 0.4768        |              |                     |                       | 0.0583        | 6          |
| Storage device Failure                                 | 0.0426        |              |                     |                       | 0.0052        | 19         |
| Personnel operation procedures                         | 0.1091        |              |                     |                       | 0.0623        | 5          |
| Emergency system Design                                | 0.3258        |              |                     |                       | 0.1860        | 2          |
| Personnel skills Training                              | 0.0379        |              |                     |                       | 0.0216        | 12         |
| Staff Life Management                                  | 0.0553        |              |                     |                       | 0.0316        | 10         |
| Close to the fairway                                   |               |              |                     |                       | 0.4719        | 1          |
| Close to the living area                               |               |              |                     |                       | 0.1522        | 8          |
| High topography storage tank area                      |               |              |                     |                       | 0.4633        | 3          |
4. Conclusion
There are three types of accidents in large-scale safety accidents: leakage accident that reaches a certain leak amount; large and complex types of combustion and explosion accidents; Toxic gas leak accident that impact area and poisoning casualty reach to a certain extent.

The major safety accidents in four kinds of hazard sources are management reason and environment factor, followed by direct cause and energy source. Company violation (management reason), Emergency system design (management reason), close to the living area (environmental factors), regional vegetation (environmental factors), and personnel operating procedures (management reasons). The failure of emergency measures and the failure of prevention and control facilities in the direct cause can not be neglected either.

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References
[1] Paltrinieri N, Dechy N, Salzano E, et al, Lessons learned from Toulouse and Buncefield disasters: from risk analysis failures to the identification of atypical scenarios through a better knowledge management, J. Risk Analysis, 32(8) (2012) 1404-1419.
[2] Zhang Wen, “Study on compensation for ecological damage of marine oil spill in China,” Ph.D. thesis, Dalian Polytechnic University, 2014.
[3] Yuan Lei, “Study on crisis communication Management in ”8.12” explosion accident of Tianjin Port,” Ph.D. thesis, Lanzhou University, 2016.
[4] Yuan Lizhi, “Analysis of leakage diffusion and risk control of large air separation tank area by PHAST,” Ph.D. thesis, East China University of Technology 2014.
[5] Chen G, Cheng S, Consequence Simulation on LNG Leakage Accidents and Its Quantitative Risk Assessment. J. Natural Gas Industry, 27(6) (2007) 133.
[6] Fu Fei, “Cause analysis and accident inversion of fuel explosion accident in tank area,” Ph.D. thesis, Dalian Polytechnic University, 2013.
[7] Ryder N L, Sutula J A, Schemel C F, et al, Consequence modeling using the fire dynamics simulator. J. Journal of hazardous materials, 115(1) (2004) 149-154.
[8] Chen Ting, Tian Shuicheng, Cong Changkui, Study on the mechanism and countermeasures of three kinds of hazard sources. J. Shanxi Coal (in Chinese), (03) (2008) 29-31.
[9] Li Dongmei, “Study on the analysis, identification and risk assessment of major hazard sources,” Ph.D. thesis, Tianjin Polytechnic University, 2009.
[10] Wang Yunhui, Xing Zhixiang, Lu Zhongqiu, Study on the consequence model of fire and explosion accident. J. Chinese Journal of Safety Sciences (in Chinese), (08) (2015) 68-74.
[11] Sang Hu. Safety technology analysis of oil storage tank. J. Chemical Management (in Chinese), (32) (2016) 344.
[12] Renni E, Krausmann E, Cozzani V. Industrial accidents triggered by lightning. J. Journal of hazardous materials, 184(1) (2010) 42-48.
[13] Chen Xiaofeng, “Study on environmental risk assessment of oil tank area,” Ph.D. thesis, Tianjin University, 2008.
[14] Chen Shuxue, “Study on risk assessment and prevention of port oil spill accident,” Ph.D. thesis, Nankai University, 2009.
[15] Chang J I, Lin C C. A study of storage tank accidents. J. Journal of loss prevention in the process industries, 19(1) (2006) 51-59.
[16] Sun Yi, Peng Shitao, Wang Xiaoli, etc, Research progress in safety early warning of storage tank area of petrochemical terminals. J. Waterway port (in Chinese), (04) (2014) 438-444.
[17] Wang Wenjun, Xi Shifeng. Brief introduction of emergency measures for environmental risk accident in storage tank area of Chemical project. J. Resource conservation and
environmental protection (in Chinese), (11) (2016) 142.

[18] Wang Qiang, “Study on safety management of petrochemical tank area based on risk,” Ph.D. thesis, China University of Petroleum, 2014.

[19] Nima Khakzad, Gabriele Landucci, Genserik Reniers. 2017. Application of dynamic Bayesian network to performance assessment of fire protection systems during domino effects. J. Reliability Engineering and System Safety, (16) (2017) 232-247.

[20] Gabriele Landucci, Amos Necci, Giacomo Antonioni et. 2016. Risk Assessment of Mitigated Domino Scenarios in Process Facilities. J. Reliability Engineering and System Safety, 160(2017) 37-53.

[21] Mu Guiqin, Yang Yangyang, Discussion on protection distance management of enterprises. J. Safety, health and Environment (in Chinese), (11) (2012) 1-3.

[22] Hu Sumei, Discussion on safety technology of tank Farms. J. Stone Depot and gas station (in Chinese), (04) (2000) 20-23.

[23] Zhou Xin, “Study on risk assessment of offshore oil spill in Port Petroleum Reserve Base,” Ph.D. thesis, Dalian Maritime University, 2015.

[24] Ghasemi A M, Nourai F, A framework for minimizing domino effect through optimum spacing of storage tanks to serve in land use planning risk assessments. J. Safety Science, 97(2017) 20-26.