Study of Application of Fault Tree Analysis Method in Safety Risk Assessment of Large-Scale Activities

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Abstract: With China's rapid economic development, the number of all kinds of large-scale activities has continued to increase, and the scale has also expanded constantly, the population have become more and more large, and the structure has become more and more complex. Therefore, safety accidents take place frequently in large activities, and cause serious casualties. In such a situation, security risk assessment of large-scale activities draws more and more attention. In this paper, the author introduced fault tree analysis method into the security risk assessment system of large-scale activities, and elaborated on the application of fault tree analysis method in every aspect of security risk assessment of large-scale activities.

1 INTRODUCTION

In the "Kummel La Festival" which was held in Nasik area of Maharashtra state of India in 2003, the situation was out of control, at least 30 persons died, and 50 persons got injured. On February 5, 2004, a crowd accident took place in Minong Park of Mayan County, Beijing, causing 37 deaths. On January 22, 2005, a serious congestion accident occurred in the Holy Land Meghan M Nile, causing about 500 injuries. The casualties and loss caused by accidents in large-scale activities were shocking. With the rapid economic development in recent years, various cultural and sports activities, exhibitions were held frequently, and the scale expanded constantly, the population and the structure also became more and more complex, such as the 2008 Beijing Olympic Games, 2010 Shanghai world expo. These events were effective propulsion of China's economic development, and brought enormous challenge to domestic security work. (Komal 2020) Good prevention work has become an urgent and arduous task for preventing accidents in large scale activities and ensuring the development of Chinese economy. Practice in risk assessment of large-scale activities in foreign countries offer us some new ideas. Compared with former experience in security job, in the safety risk assessment of large-scale activities, various factors affecting the occurrence of risk are analyzed, the probability of accidents and accident consequences are predicted through the use of historical data, and risks of large-scale activities are quantified. In this way, the security work has minimum risk.

The fault tree analysis method, also known as the method of accident tree analysis, abbreviated as FTA, is one of the important analysis methods of safety system engineering, it can carry out identification and risk evaluation of various systems, analyze the direct cause of the accident, and reveal the potential causes. Fault tree method is clear and logic in the description of the causal relationship in the accident. It can be used for qualitative analysis, and quantitative analysis, and is often used to solve reliability problem in complex system, and can also be used for risk assessment. (Yazdi, Korhan, Daneshvar 2020) Because the cause of the accident in large-scale activities is a complex system, the introduction of the fault tree analysis method into the security risk assessment of large-scale activities has practical significance.

2 FAULT TREE ANALYSIS METHOD

Fault tree analysis was firstly proposed by A · B · Mines from American Baer telephone laboratory in 1962.At that time, it was mainly used

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in research on the control system of missile launcher. In 1974, American Atomic Energy Commission carried out a risk assessment on a nuclear power plant accident with the use of fault tree analysis method, published the famous "Lampson report". The report involved extensive application of fault tree analysis for the first time, and was a great success. Since then, the method of fault tree analysis caused great repercussions and received wide attention, thus was applied and promoted in many countries and enterprises. In China, the introduction and study the method of fault tree analysis began in 1976, at present, it has been applied and promoted in many sectors and enterprises, and achieved great progress. (Onur, Elifcan 2021) At the end of the 80's, the fault tree analysis method was applied in safe production and labour protection of the railway transportation system, and good results was achieved. And now, the fault tree analysis method is also widely applied in nuclear industry, aerospace, machinery, electronics, shipbuilding, chemical industry and other fields.

The method of fault tree analysis adopts inverse method of causal relationship, and is the deductive reasoning that adapt to human thinking habits. The method of fault tree analysis starts from results (top events) to causes (lower level events), until decomposition ends. In the process of analysis, a particular accident (top event) is connected with causes at various levels (lower level events) with logic gate symbols, thus getting a tree graph (namely fault tree) that describes the logical relations in a vivid and brief way. Then the analysis and assessment are conducted through simplification of the fault tree and calculation.

3 THE APPLICATION OF FTA IN PREPARATION STAGE OF SECURITY RISK ASSESSMENT IN LARGE-SCALE ACTIVITIES

To carry out an accurate security risk assessment of large-scale activities, it is necessary to do a preparatory job before the evaluation. Careful analysis of reasons for safety accidents of large-scale activities and the accumulation of evaluation materials need to be done. At this stage, the fault tree analysis method can be introduced for the fault tree modelling of various safety accidents in large-scale activities. The establishment of the fault tree has the following steps:

3.1 Determine the Top Event

Top event is the accident to be analyzed. In the risk assessment of large activities, top events are various accidents that may occur in large-scale activities, including fire accident, crowd accident, etc. It should be noted that, when selecting top events, it is necessary to concentrate on certain kind of accident, because large events accident is a enough broad concept, and is not conductive to the establishment of a fault tree model. (Zhang, Yin 2020) When selecting top events, data on the possibility of the occurrence of accidents and severity of accidents need to be prepared.

3.2 Investigation on Various Reason Incidents

Reason events are all direct reasons and factors related to the accident. After determining top events, in order to prepare the fault tree, it is of great necessity to find out all direct causes for the top events. As mentioned above, various safety accidents in large scale activities have complex factors, including human factors, material factors, environmental factors, management factors, etc. In conducting the investigation, investigation and data statistics methods can be applied. Investigation results must be truthful, objective and comprehensive.

3.3 Drawing Fault Tree

After finding various reasons for top events, appropriate event symbols and logic gates can be used to connect and analyze them until the most basic reason event is found, in this way, a fault tree is formed.

When connecting reason events of different levels, if the top events occur only when all the lower level events take place, the "and" symbol is used. If the top events occur when one underlying event occur, then "or" symbol is used. Connection of logic gate is very important in fault tree, it relates to the logical relationship between various events, directly affects qualitative analysis and quantitative analysis of the fault tree. (Shahabuddin, Mat Bistaman, Subri 2020) The logical relationship between various event should be strict, reasonable, repeated deliberation, modification, and even restart are needed in the process of drawing the fault tree, until it is in line with the actual situation.

Once the fault tree model of all kinds of accidents is established, the fault tree analysis can

be formed. The main purpose of the fault tree analysis is to find out the relationship between basic events and top events, and between different basic events, thus reach corresponding conclusions and offer the basis for security risk assessment of large events and the development of countermeasures. The main content of analysis is simplification of the structure of the fault tree, obtain minimum cut sets and the minimal path sets, determine ordering of the structure importance of each basic event, then find out the probability of each basic event through statistical data or expert data, and calculate the probability, importance and critical importance degree of the top events.

3.4 Minimum Cut Set

In the fault tree, the collections of basic events that can lead to the occurrence of top events are called cut set. Minimum cut sets is a set of basic events that cause the occurrence of top events, namely, top event will not take place if any of the basic events in the minimum cut set does not occur. One minimum cut set represents an accident model, and all the minimal cut sets represent all accident models.

In the fault tree analysis, first of all, find out all the minimal cut sets of the fault tree. Figure out all possibilities of top events. The treatment of the fault tree is generally carried out with the use of the Boolean algebra law, starting from the basic events, and determine the logic relationship between all the accidents according logic gates of the fault tree. (Komal 2020) The logic gate "and" means that output event occurs only when connected events both happen, the symbol is "∩". The logic gate "or" means that the output event occur when any of connected events happen, the symbol is "∪".

We judge from the number of minimal cut sets, generally, the more minimum cut sets, the more occurrence models for top events, and more risks for accident system. From the combination of minimum cut sets, the combination of basic events in the minimal cut sets represent the ways for occurrence of accident, and the key factors causing the occurrence of accident can be found based on this.

3.5 Minimum Path Sets

In the fault tree, the collection of basic events that cannot cause the minimum possibility of occurrence for top events is called minimum path set. In the minimum path set, the removal of any basic event cannot guarantee any accident, therefore the minimal path collection represents the safety and reliability of the system. In order to obtain a minimal path set, the fault tree is transformed into a duality success tree, and various accidents cannot occur, at the same time, "or" gate in the fault tree is replaced with "and" gate, and "and" gate is replaced with "or" gate, thus obtaining a success tree. The minimum cut set of the success tree is the minimum path set of the fault tree.

If the minimum path contains many basic events, it means that accident prevention need to be done from many aspects. If the minimum path contains less basic events, it means the system is highly safe, and accident prevention is easy.

3.6 Structure Importance Degree

Structure importance is the importance of each basic event based on the analysis of the fault tree. Namely, the influence degree of the occurrence of each basic event on top events is analyzed, assuming each basic event has equal probability of occurrence. Structure importance is the influence degree of each basic event on top event, based on the analysis of the fault tree structure, without considering the probability of basic events, therefore, structure importance is not related to the probability of bottom events, and it is a qualitative importance analysis.

Structure importance of each basic event can be judged based on minimum cut sets and minimum path sets. In general, basic events in minimal cut set that contains a single event has the largest structure importance. (Gachlou, Roozbahani, Banihabib 2019) And structure importance coefficient of other events is determined by the times of appearance in the minimal cut set. More occurrences mean a larger structure importance coefficient, and less occurrences means a smaller structure importance coefficient. If a basic event has a large structure importance, its impact on top event is bigger, and it should be the focus of prevention.

3.7 The Probability of Top Event

In order to obtain the probability of top event, it is necessary to obtain the probability of each basic event first. There are two ways: one is expert inference method, namely professional personnel who have a lot of experience in the field give the probability of each basic event. (Abbasi, Allahviranloo 2021) Second, collect some cases of accidents that occur during a period of time, do classified statistics of causes, thus obtain the probability of each basic event. Then calculate the probability of intermediate events according the

fault tree and the logic relationship, thus obtain the probability of top event.

Probability of top event is basic data for the quantitative analysis of the fault tree, and important evidence for the quantitative risk assessment of the system.It should have a good accuracy. The gap between the probability obtained and actual situation should be within the reasonable error range, so as to the guarantee of the accuracy of the data.

3.8 Probability Importance

It refers to change degree of probability for the occurrence of top event caused by probability change of basic event. A partial derivative of probability function of each basic event of each variable can produce probability importance coefficient of the basic event.

In case of independent bottom events, probability importance of a bottom event means change rate of occurrence probability of top event caused by minor change of occurrence probability of the bottom event. Larger probability importance means the larger impact on top event.

3.9 Critical Importance Degree

In general, the control of event with larger occurrence probability is easier than event with smaller occurrence probability. And the contribution of cut set of probability importance and basic events cannot reflect the problem. Therefore, it is necessary to carry out a critical importance analysis.

In principle, the analysis of the fault tree involves the 6 basic contents. Analysis about minimum cut sets, minimum path sets and structure importance degree is qualitative analysis, and analysis of top event probability, probability importance degree, and critical importance is quantitative analysis. In specific analysis, different steps, qualitative analysis, semi quantitative analysis and quantitative analysis can be chosen according to various analysis purposes, manpower and material input, analyzing ability, as well as basic dataavailable.

4 THE APPLICATION OF FTA IN IMPLEMENTATION STAGE OF SAFETY RISK ASSESSMENT OF LARGE-SCALE EVENTS

In fact, the security risk assessment of large-scale activities is already a very mature business projects in foreign countries, especially the developed countries, but in our country, the introduction of security risk assessment of large-scale events has a short history. Over the years, public security organs mainly adopt experience-type management in large public events. But in recent years, safety risk evaluation of large activities draws more and more attention in China. For example, on September 9, 2005, the Beijing Municipal People's Congress passed the "Regulations on safety management of large-scale social activities in Beijing City", which required organizers of large-scale activities to carry out the risk assessment, submit risk assessment reports, develop safety work plans, and emergency disposal pre-plan for the first time. In 2008 Beijing Olympic Games, in the application of a security risk assessment, some progress was made.

The introduction of fault tree analysis method which is widely used in system safety engineering into security risk assessment of large-scale events is an innovation. (Jeba, Johnraja, Jebaveerasingh 2021) The fault tree analysis method can identify all kinds of accident risks of large-scale activities, find out key cause of accident, and help obtain accurate risk evaluation results, and at the same time, put forward risk countermeasures.

(1) The application in safety risk identification stage of large-scale activities

Risk identification is the prerequisite and basis for risk assessment. Timely, comprehensive, accurate access to information, identification of accident types, influence factors, accident mechanism of large-scale activities are necessary for accurate risk evaluation results, taking right decisions and implementing targeted safety measures. Safety accidents of large activities have many kinds and have complex causes. They are huge systems with man, machine, and environment interacting with each other.

In identification of safety risk of large events, if there are no clear classification and objectives, the final conclusion will be useless. In the application of the fault tree analysis method, the focus of assessment objective is accidents of higher risks. For example, in temple fair, performances and other large activities, the focus is on the assessment of fire accident, in contrast in some comprehensive and large exhibitions, many types of accidents are evaluated to get clear objectives and focus in risk recognition.

After forming the fault tree for various types of accidents in large-scale activities, all relevant factors have been clear, the logic relationship between

various factors and the accident has been determined, therefore, the identification of various risks should be based on the fault tree of various accidents, with each bottom event as the object. At the same time, a great attention is paid to factors with large structure importance, probability importance degree, critical importance degree based on the conclusion of the fault tree analysis.

(2) The application in security risk evaluation stage of large-scale activities.

Risk evaluation is the selection of scientific, reasonable, applicable risk assessment methods and assessment classification according to characteristics of accident, probability of accident, and influence of dangerous factors. Risk assessment mainly has three ways: qualitative evaluation method, quantitative evaluation method and semi quantitative method.

The qualitative evaluation method refers to the qualitative analysis of the characteristics, activities, organization and management, and participants of large-scale events. This is based on experience and intuition. The evaluation results include some qualitative indicators, such as compliance with safety indicators, accidents, and accidents that caused the accident. In the past practice, the qualitative evaluation method is widely used in the safety risk evaluation of large-scale activities. Although the method is simple, easy to understand, and easy to learn, its conclusions have certain limitations. Sometimes, evaluators may differ from each other for different reasons and different evaluation results.

In quantitative evaluation method, a lot of experimental results and accident data are analyzed. Personnel capacity, security management situation, facilities and other aspects of large-scale activities are calculated quantitatively. The assessment results are some quantitative indexes, such as occurrence probability of accident, accident injury (or damage) range, quantitative risks, accident relevance or importance of leading factors, Obviously, the conclusion from the fault tree analysis belongs to quantitative results, therefore, quantitative evaluation method applies to the risk assessment of fault tree analysis. Due to limited conditions, fault tree analysis can only reach the qualitative analysis stage, and its conclusions about the minimum cut set, minimum path set, and structural importance are also applicable to semi-quantitative evaluation methods. The results from quantitative or semi quantitative evaluation are more scientific than qualitative evaluation results.

The main content of quantitative risk assessment is risk calculation. The basic idea of risk calculation is based on mathematical relationship of the theory of risk: risk degree = accident probability* accident severity. If we can calculate accurate risk degree, we can carry out more precise risk classification with the accurate risk degree, and set an accurate warning threshold.

(3) The application in stage of risk countermeasures development of large-scale activities.

Development of risk countermeasure refers to scientific deployment of resources and the development of security implementation scheme and emergency plan according to risk assessment results. Risk countermeasures include reducing the possibility of accidents and reducing accident severity. The possibility of accident refers to the probability of accident. To reduce the possibility of accidents is to reduce the probability of accident. To reduce the severity of accident, it is necessary to take surrounding environment into account. If a building collapses, and there is no people around, it will not cause any casualty. If the personnel density is high, it will lead to a large number of casualties. Two different environments mean different severity accidents.

Using the fault tree to develop risk countermeasures, all possible solutions of reducing accident probability can be found on the basis of minimum cut sets, and then choose the best solution. The best solution for eradicating accidents can be found based on minimal path sets to reduce the possibility of accident. The important points and ranking of countermeasures can be determined according to importance (importance coefficient) analysis, so as to enhance the prevention efficiency. The comparison of early-warning threshold value is conductive to the establishment of early warning mechanism and the improvement of preventing capacity.

5 CONCLUSION

Fault tree analysis method has been used for analysis and risk assessment of industrial production accidents for many years, obvious effects have been achieved. Since the 60s of the twentieth century, the development of fault tree has been more and more mature, and its application has extended to different fields such as aerospace and nuclear industry. But the introduction of the fault tree analysis method

into the safety management of large-scale activities is only made in recent years, it is a new field.

(1) After the above discussion, we can see that the use of the fault tree analysis method in safety risk of large-scale activities has certain feasibility, since compared to other methods, it has specific advantages.

(2) The use of fault tree analysis was to analyze all kinds of safety accidents in large scale activities can help understand the accident system, find the key links of accident, and key points of high risks, enhance the accuracy of safety risk assessment. Targeted risk countermeasures can be proposed through the fault tree analysis, making assessment activities more efficient.

(3) In this paper, taking crowd accidents as an example, the author tried to construct the fault tree, and carry out qualitative and quantitative analysis. In the practice process, it was found that the fault tree method involves a large amount of calculation. In the future, with the aid of computer, the calculation can be easier.

(4) The security risk assessment of major events will become an inevitable trend, but at present, the safety risk assessment of large-scale activities has many problems, especially in some basic work. The author has consulted a large number of literatures, trying to find out the statistical data of various accidents, but the data is incomplete and the statistical methods are not standardized. In order to promote the security risk assessment in large-scale activities, a good job in data statistics is needed.

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REFERENCES

Abbasi F., Allahviranloo T.. (2021) Estimation of Failure Using Fault Tree Analysis Based on New Operations on LR-Type Flat Fuzzy Numbers. New Mathematics and Natural Computation,17: 72–81.

Derse Onur, Göçmen Elifcan. (2021) Transportation mode choice using fault tree analysis and mathematical modeling approach. Journal of Transportation Safety & Security,136: 102–109.

Komal. (2020) Fuzzy fault tree analysis for controlling robot-related accidents involving humans in industrial plants: a case study. International Journal of Quality Reliability Management.,38: 169–178.

Komal. (2020) Fuzzy fault tree analysis for controlling robot-related accidents involving humans in industrial plants: a case study. The International Journal of Quality & Reliability Management,2021,38: 125–134.

Leelipushpam Getzi Jeba, Jebadurai Immanuel Johnraja, Jebadurai Jebaveerasingh. (2021) Fault Tree Analysis based Virtual Machine Migration for Fault-Tolerant Cloud Data Center. Journal of Integrated Design and Process Science,123:87–98.

MohdZaki B. Shahabuddin, IzwanNurli B. Mat Bistaman, NorIzham B. Subri. (2020) Fault Tree Analysis to Measure WSN Connectivity Reliability. Journal of Physics: Conference Series,159: 24–39.

Mahdi Gachlou, Abbas Roozbahani, Mohammad Ebrahim Banihabib. (2019) Comprehensive risk assessment of river basins using Fault Tree Analysis. Journal of Hydrology35: 19–28.

Mohammad Yazdi, Orhan Korhan, SahandDaneshvar. (2020) Application of fuzzy fault tree analysis based on modified fuzzy AHP and fuzzy TOPSIS for fire and explosion in the process industry. International Journal of Occupational Safety and Ergonomics,26: 62–73.

Qicheng Zhang Xiaobei Yin. (2020) Research on the Application Status and Trend of Fault Tree Analysis based on CiteSpace. World Scientific Research Journal,62: 43–56.