International Core Journal of Engineering Volume 6 Issue 9, 2020
ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0039

Research on LNG Maritime Transportation Risk Analysis Based on FSA Method

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Abstract

At present, my country is developing towards green, diversified and low-carbon in the concept of national energy strategy, and pay more attention to the safety of energy supply and the protection of the ecological environment. Liquefied natural gas (LNG) is a relatively advanced energy source. As an efficient and low-carbon clean energy, it gradually dominates the world's energy system, and my country's demand for natural gas is increasing. As a clean energy source, LNG has a very serious accident once it leaks. In order to reduce and prevent safety accidents during LNG transportation, this article will conduct research and analysis on the risk factors of LNG marine transportation, and use the comprehensive evaluation method (FSA) to study the risk factors from the four aspects of "man-machine-environment-pipe". At the same time, based on the basic theory of the fault tree analysis method, a fault tree model of LNG marine transportation leakage accidents is established. Using the qualitative analysis method, the minimum cut set, minimum diameter set of the entire model and the structural importance coefficient of each basic event are calculated. Finally, based on the risk analysis content, corresponding control and preventive measures are proposed to ensure that LNG is transported at sea safety.

Keywords

LNG leakage; FSA method; Risk analysis; Fault tree analysis.

1. Introduction

Climate warming, melting glaciers, and rising sea levels are global problems. In order to alleviate the energy crisis and protect the ecological environment, countries are looking for clean fuels that can replace oil and coal. Since the storage of natural gas is relatively abundant, the products of its combustion are basically water and carbon dioxide, and there is little pollution to the environment. The demand for natural gas in many countries is increasing. According to the global Platts report data, Asia is the world's largest demand side, accounting for about 70% of global demand, of which China can be regarded as the world's fastest growing demand for LNG.

Table 1. China Natural Gas Production and Sales Data (Unit: 100 million cubic meters)

Years	2013	2014	2015	2016	2017	2018	The first ten months of 2019
Production	1178	1280	1298	1371	1487	1583	1423
Import volume	530	595	621	721	920	1237	1068
Apparent consumption	1676	1803	1840	2058	2373	2787	2463

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As can be seen from Table 1, with the country's further increase in demand for clean energy, natural gas demand increased year-on-year. Natural gas production in the first ten months of 2019 was 142.3 billion cubic meters, an increase of 10.3% year-on-year, and natural gas imports were 106.8 billion cubic meters. The year-on-year growth was 8.2%, and the apparent consumption was 246.3 billion cubic meters, an increase of 9.5% year-on-year.

Imported LNG can effectively solve the ecological and environmental problems and the current energy shortage. Environmental pollution restricts the development of many construction projects, so in industry and daily life, LNG has become the main choice. As a clean new energy source, LNG is accompanied by many potential dangers during transportation, which deserves high attention, because the consequences of LNG leakage are unimaginable and unaffordable, involving a wide range and extremely harmful. Therefore, it is very necessary to systematically study the risk factors in the process of LNG transportation. It is important to ensure the safety of LNG transportation by analyzing and proposing preventive measures to reduce transportation safety accidents.

2. Related concepts

2.1 The nature and danger of LNG

The main component of liquefied natural gas [1] is methane, which is a multi-component mixture dominated by hydrocarbons. It is colorless, odorless, non-toxic and non-corrosive, with a density lower than water and a liquid-to-volume ratio of 625:1. Compared with the same volume of natural gas, the storage space of LNG is small, which is convenient for long-distance transportation. As a relatively advanced new energy source, the air pollution caused by LNG combustion is very small, but the energy released is very large.

Because the energy stored in LNG is very large, it is extremely dangerous. Once a leak occurs, meeting certain conditions will cause fire or explosion, and the heat radiation will cause serious damage. Leakage on the sea surface will cause boiling phenomenon. Once humans inhale excessive amounts of LNG, they will Headaches, confusion, difficulty breathing, and severe death can cause suffocation; direct contact with LNG on human skin can cause frostbite; it can damage transport ships and cause hull rupture.

2.2 LNG ship definition

The LNG ship is a special vessel for transporting liquefied natural gas. It is a product with high technology, high difficulty, and high added value [2]. The main consideration in the design of the ship is the ability to adapt to low-temperature media materials. In order to be able to adapt to low temperatures, the storage tank of the LNG ship is a special structure independent of the hull. The service life is generally 40-45 years. The storage tank system of the world LNG ship There are two types of self-supporting and membrane [3].

3. Risk Analysis and Model Construction of LNG Transportation Leak

3.1 Man-machine-ring-tube

The leakage problems that occur in LNG marine transportation are related to personnel factors, ship factors, environmental factors, and management factors. Through the analysis of LNG leakage accident data, human risk factors are the key to the accident. Nearly 80% of marine accidents are due to human unsafe behavior, such as weak professional knowledge of staff, illegal operations, and poor quality. In terms of machinery, due to the aging and corrosion of the ship's equipment, the hull structure is broken. These risk factors also largely affect the transportation safety of LNG; in terms of environmental factors, sudden natural disasters will also have an impact to a certain extent; finally In terms of management factors, inadequate training and management of employees and the incomplete management and supervision system all restrict the safety of transportation.

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3.2 Basic Theory of Fault Tree

Fault tree analysis (FTA) is a very important accident analysis method in safety system engineering. It can accurately identify the risk factors that exist in the entire system and conduct a detailed risk assessment. Fault tree analysis can make the causal relationship between various risk factors more intuitive and specific, with strong logic. Through the analysis results, corresponding measures can be formulated more effectively to improve the safety and efficiency of the system. The basic steps of the fault tree analysis method are shown in Figure 1 [4]:

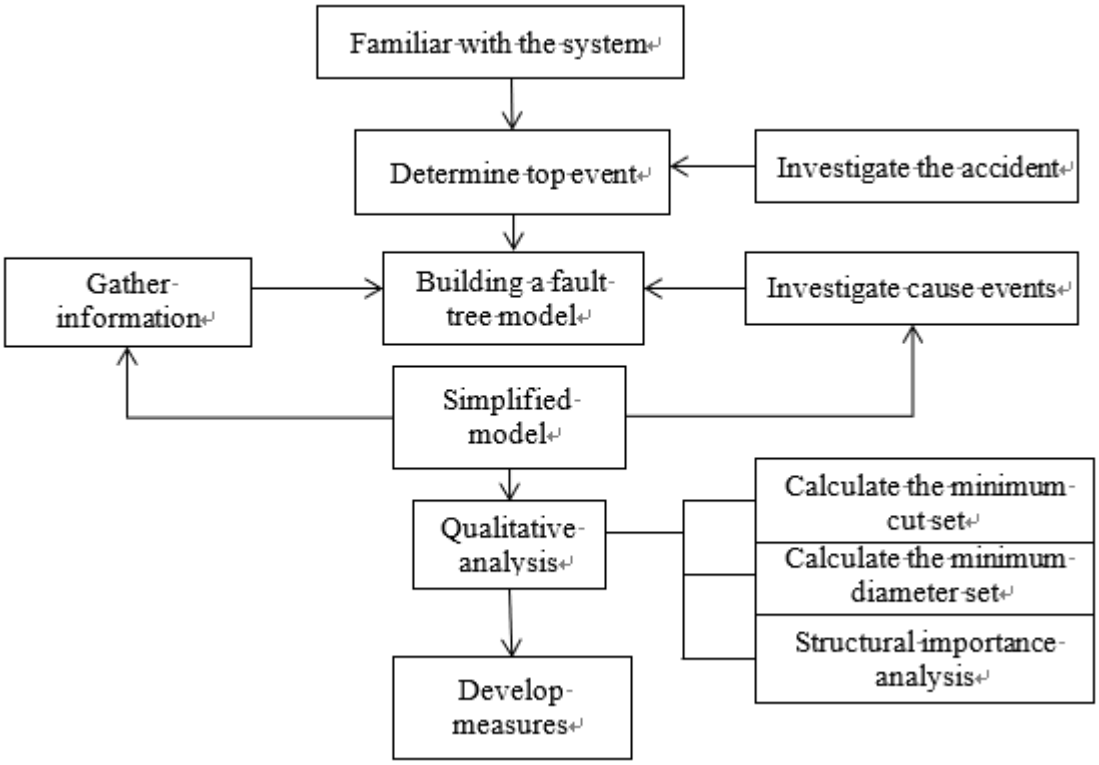

Figure 1. Basic steps of fault tree analysis

3.3 Construction of LNG leakage fault tree model

Based on the analysis of the causes of leakage accidents in LNG marine transportation, we determined the overhead events, intermediate events, and basic events, and used the overhead events as the output of the logic gate, where the direct cause of the accident was used as the input event. According to the deductive analysis, The direct cause events are connected to form an accident tree, and the top-level events are analyzed from top to bottom [5]. According to the specific theory, the fault tree model is constructed, as shown in Figure 2.

The types of events represented by each symbol in the transportation leak fault tree model are:

T--LNG transportation leak; A1--Human factors; A2--Ship factors; A3--Environmental factors; A4--Management factors; B1--Crew quality; B2--Professional knowledge; B3--Hull structure damage; B4--LNG storage tank leak; B5--Failure to comply; X1--Poor working quality; X2--Poor psychological quality; X3--Poor physical fitness; X4--Weak response to accidents; X5--Unfamiliar manipulation technology; X6--Illegal operation; X7--Weak legal awareness; X8--Weak security awareness; X9--Equipment not maintained on time; X10--Heavy impact damage; X11--Aging corrosion; X12--Tank collision; X13--Quality is not up to standard; X14--High pressure in the tank; X15--Heavy fog; X16--Thunderstorm; X17--Tropical cyclone; X18--Insufficient training; X19--Automatic monitoring equipment off; X20--Violation of safety regulations; X21--Improperly managed equipment; X22-- Lack of management and supervision system

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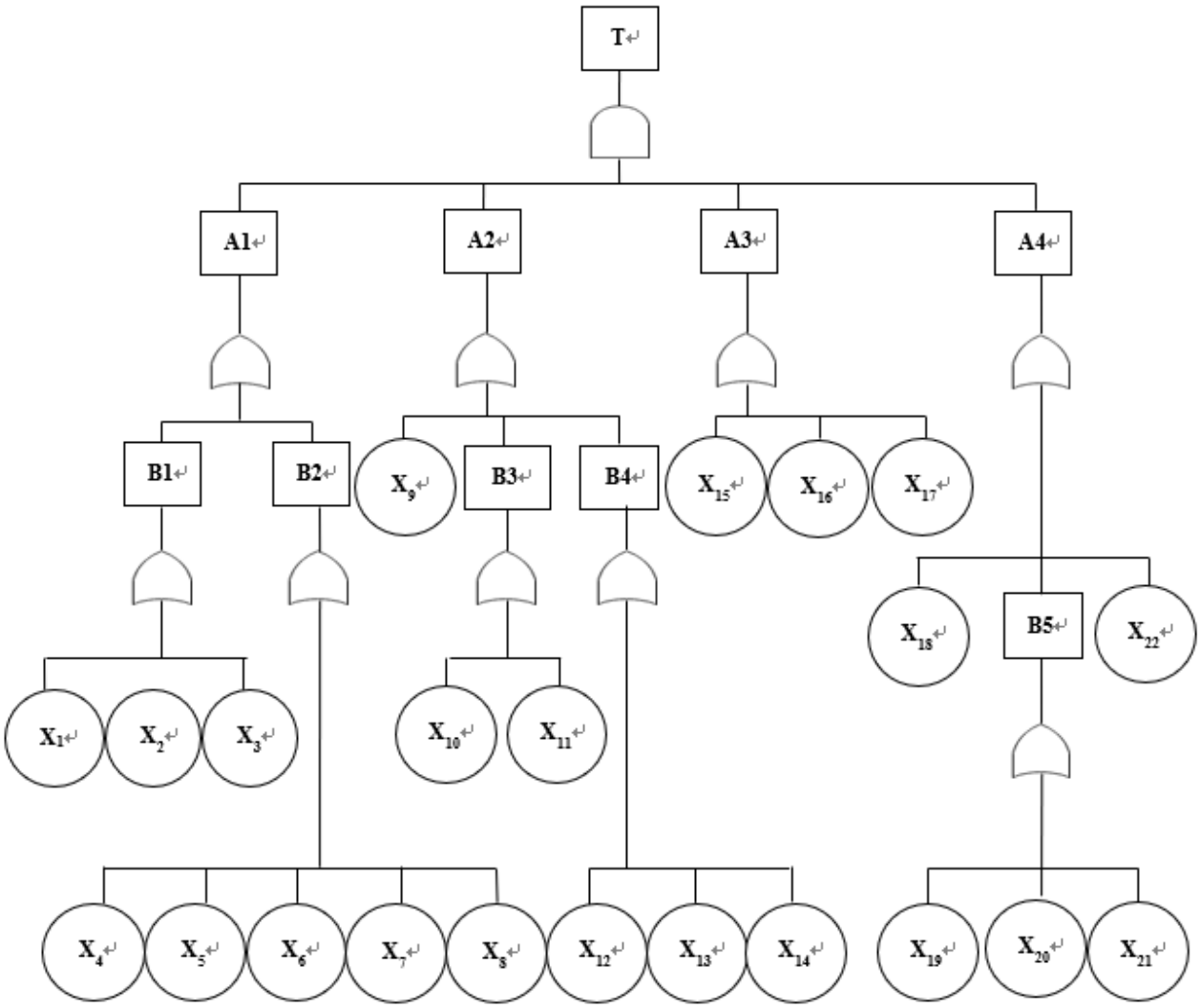

Figure 2. LNG Transportation Leakage Fault Tree Model

3.3.1 Minimal cut set

It can be seen from Figure 2 that in the fault tree of LNG marine transportation leakage, there are 9 intermediate events and 22 basic events. According to the basic theory of the fault tree, a structure function at each level can be obtained through the relationship of each event [6].

The top event structure function formula:

$$T=A1\times A2\times A3\times A4 \quad (1)$$

A-level fault tree structure function formula:

$$A1=B1+B2;\ A2=X9+B3+B4;\ A3=X15+X16+X17;$$
$$A4=X18+B5+X22 \quad (2)$$

A-level fault tree structure function formula:

$$B1=X1+X2+X3;\ B2=X4+X5+X6+X7+X8;$$
$$B3=X12+X13+X14;\ B5=X19+X20+X21 \quad (3)$$

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Cut sets [7] are the set of basic events that cause overhead events to occur, and the minimum set of basic events that cause overhead events to occur is called the minimum cut set. The principle of the minimum cut set algorithm is to start from the top event, from top to bottom, and the AND gate increases the order of the cut set, or the gate increases the number of cut sets. The more minimum cut sets in a fault tree, the higher the risk factor of the system. According to cut set theory, the smaller the cut set order, the greater the probability of a dangerous accident, and the greater the impact on the overhead event, which is the weak link of the entire system. Substitute Equation 2 and Equation 3 into Equation 1 to expand. At the same time, the distribution law and commutation law of Boolean algebra operation are used to simplify the calculation result to obtain the minimum cut set. There are a total of 720 minimum cut sets in the LNG leakage fault tree, which is equivalent to a total of 720 basic event combinations leading to leakage accidents during LNG marine transportation, causing harm.

3.3.2 Minimum diameter set

Contrary to the definition of the minimum cut set, the minimum path set [8] refers to the minimum set of basic events required for the top event not to occur. The method is to use the dual tree and the success tree, that is, replace the occurrence of events on the top of the original fault tree with non-occurrence, replace the OR gate with an AND gate, and replace the AND gate with an OR gate, find the success tree of the original fault tree dual, find The minimum cut set of the success tree is the minimum path set of the fault tree. According to the Boolean algebra duality principle A×B=A+B, the minimum diameter set is obtained as:

$$T'=A1'+A2'+A3'+A4' \tag{4}$$

According to the calculations, four minimum diameter sets are obtained: {X1, X2, X3, X4, X5, X6, X7, X8}; {X9, X10, X11, X12, X13, X14}; {X15, X16, X17}; {X18, X19, X20, X21, X22}, in order to prevent LNG from leaking during sea transportation, at least one of them should not occur as a whole.

3.3.3 Structural importance analysis

Structural importance analysis [9] refers to analyzing the impact degree of each basic event on the occurrence of the top event only from the fault tree structure without considering the probability of the occurrence of the basic event, and finally relying on the analyzed results Formulate measures to improve the security of the system. Through the previous calculations, 720 minimum cut sets and 4 minimum diameter sets in the LNG marine transportation leakage accident model have been obtained. Finally, the minimum diameter set is used to analyze the structural importance of the basic events of the LNG marine transportation leakage fault tree. Calculate the importance coefficient of the basic event structure according to the following formula [10]:

$$I(X_i) = \sum_{X_i \in S_j} \frac{1}{2^{n_j-1}} \tag{5}$$

Formula: $I(X_i)$-- The structural importance coefficient of the basic event X_i;

$X_i \in S_j$-- The basic event X_i belongs to the smallest path set S_j;

n_j-- The number of basic events included in the minimum path set S_j.

The importance coefficient of each basic event is calculated by formula 5:

$$I(X_1) = I(X_2) = \ldots\ldots = I(X_8) = 1/2^{8-1} = 1/2^7$$
$$I(X_9) = I(X_{10}) = \ldots\ldots = I(X_{14}) = 1/2^{6-1} = 1/2^5$$
$$I(X_{15}) = I(X_{16}) = I(X_{17}) = 1/2^{3-1} = 1/4$$
$$I(X_{18}) = I(X_{19}) = \ldots\ldots = I(X_{22}) = 1/2^{5-1} = 1/2^4$$

From the above calculation results, the sequence size of structural importance is:

ISSN: 2414-1895 DOI: 10.6919/ICJE.202009_6(9).0039

$$I(X15)=I(X16)=I(X17)> I(X18)=I(X19)=……=I(X22)> I(X9)=I(X10)=……=I(X14)> I(X1)=I(X2)=……=I(X8)$$

3.4 Preventive measures for LNG marine transportation leakage accidents

According to the calculation and analysis of the LNG leakage fault tree, 720 minimum cut sets and 4 minimum diameter sets are obtained. It can be seen that there are many reasons for LNG transportation leakage accidents, but there are few control methods. LNG marine transportation has a higher risk, and effective safety measures are proposed based on the results.

(1) Precise supervision of LNG ships. The weather on the sea is changeable and bad weather is prone to occur. Thunderstorms, heavy rain, typhoons and other severe weather severely affect the navigation safety of ships. For LNG ships, the Maritime Safety Administration should specially formulate a "VIP" service to achieve early deployment, key supervision and strong wind warning , Special personnel and special desks, all-round supervision, closely monitor the sea transportation of LNG ships, and escort accurately.

(2) Improve the quality of LNG ship crews and strengthen training. LNG transportation is full of many potential hazards, requiring relevant personnel to have strong professional knowledge and operational skills, to calmly take appropriate economic hedging measures in the event of an accident, to prevent staff from operating erroneously, and relevant regulatory authorities should regularly Organize security drills.

(3) Regular maintenance of ship equipment to reduce the incidence of machine failures. The crew should regularly inspect the machinery and equipment and report it in time to ensure the good operation of the equipment. The production of LNG storage tanks must meet the national safety standards and carry out authoritative safety appraisal.

(4) Strengthen management efforts and establish a complete safety management system. Before and after the accident, there should be a corresponding safety management system. During the entire transportation, the crew must strictly follow the safety rules.

4. Conclusion

In recent years, the demand for LNG has been increasing, the LNG shipping business has also increased, and the risk of leakage has increased accordingly. In this paper, the fault tree analysis method is used to comprehensively study the risk of LNG marine transportation leakage accidents, calculation and analysis, find out the important causes of leakage accidents, and put forward safety countermeasures, which is of great significance to ensure the safe transportation of LNG at sea.

Acknowledgments

First of all, I am very grateful to my teacher. During my writing, I gave me many suggestions and taught me carefully so that I can successfully complete the paper. Secondly, I am very grateful to my classmates. We encourage each other, learn from each other, and make progress together. Finally, I want to thank my family for their encouragement and support.

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