World Scientific Research Journal Volume 7 Issue 11, 2021
ISSN: 2472-3703 DOI: 10.6911/WSRJ.202111_7(11).0034

# Research Progress on Acceptable Risk Criteria

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## Abstract

**The research and formulation of risk acceptance standards are of great significance to various fields and industries. System in this paper the definition and classification of risk acceptance criteria is introduced, and design method of risk acceptance criteria and ships and other areas of risk acceptance criteria research progress, and especially to the existing research method F - N curve analysis and prospect, summed up the F - N curve combined with the method of risk acceptance criteria in areas of ship.**

## Keywords

**Risk acceptable standard; Personal risk; Social risk; Risk analysis.**

## 1. INTRODUCTION

With the development of social economy and the improvement of the level of navigation science and technology, maritime transport ships present the trend of large-scale, high-speed and specialized development. Ship is an important means of transport in modern society, carrying around the volume of international trade cargo, so the safety and environmental protection of ship transport has been the focus of attention. However, serious Marine accidents and pollution accidents occur from time to time, which causes great concern to the safety of maritime navigation and Marine environmental pollution. Throughout the decades of revision of conventions and regulations on ship safety and pollution prevention, it can be found that they are almost closely related to a disaster and accident. Although each revision of the convention and rules has played an important role, the traditional practice of passively waiting until an accident occurs to revise after the event has gradually aroused people's thinking. The study of risk acceptance criteria becomes particularly important.

## 2. RISK ACCEPTANCE CRITERIA

In risk analysis, risk acceptance Criteria refers to the acceptable risk level within the specified time or in a certain behavior stage of the system. It directly provides a reference basis for risk analysis and the formulation of risk reduction measures, so it should be given in advance during risk analysis. Risk acceptance criteria can be expressed quantitatively or qualitatively, depending on how the risk is expressed [1]. A number of agencies and departments, represented by the UK Health and Safety Committee, have done a lot of work in this area and have produced fruitful research results. Health and Safety Executive proposed ALARP criterion to distinguish risks. [2]. Risk acceptance criteria can be classified into three categories [3]: personal risk acceptance criteria, social risk acceptance criteria and environmental risk acceptance criteria.

### 2.1. Individual Risk Acceptance Criteria

Personal risk refers to the frequency with which a particular hazard is exposed to an unprotected person living in a particular location for a long period of time. [4] Generally

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202111_7(11).0034

speaking, the risk here refers to the risk of death, and a specific period refers to one year or a person's lifetime. For an offshore platform, it is the remaining life cycle of the platform. Personal risk is highly subjective, depending on personal preference [5], namely the individual risk has the characteristics of voluntary, according to the character of the people engaged in the activity, the risk can be divided into two categories, voluntary and involuntary, it depends on the result in the risk of operation is controlled by the people, it is thought that voluntary risk can be controlled, you can't control risk of involuntary. For passenger ships and transport ships such as liquefied gas ships, passenger ships are less dangerous than liquefied gas ships, but the number of personnel is more than liquefied gas ships. Due to these differences, passenger ships and transport ships need to be classified and evaluated.

According to standards published by the Health and Safety Executive [6], the following risk criteria can be proposed for ships, as shown in Table 1.

**Table 1.** Risk criteria of ships

| Different groups | Value at risk |
|---|---|
| Maximum risk for crew | 10-3 per year |
| Maximum risk for passenger | 10-4 per year |
| Maximum risk for coastal public | 10-4 per year |
| Negligible risk | 10-6 per year |

### 2.2. Social Risk Acceptance Criteria

Social risk is used to describe the relationship between the probability of accident occurrence and the number of people injured or killed by accident. Social risk acceptance criteria are designed to limit the risks of ships to society as a whole and to local communities (such as ports) that may be affected by ship activities. In particular, society is concerned about risks in areas where ships operate, so social risk acceptance criteria are used to limit the risk of disasters that simultaneously affect many people. In fact, the standard defines the term "acceptable level of risk" in terms of the overall social risk of death.

### 2.3. Environmental Risk Acceptance Criteria

Environmental risks are different from general risks, because the environment is exposed to various activities, which may affect the environment, such as oil leakage of oil tanker, fire and explosion of liquefied gas tanker, etc. Compared with other methods of determining risk acceptance criteria, the determination method of environmental risk acceptance criteria is more standardized.

## 3. RESEARCH METHODS OF RISK ACCEPTANCE CRITERIA

In the field of ship traffic, there will be some risks in the industry, resulting in accidents. Since risk cannot be reduced to zero, risk reduction requires certain economic support, and in production, economic benefit is the main purpose of production, so the balance between risk reduction and production is particularly important. To reduce risk, risk acceptance criteria need to be set. At present, the methods to determine risk acceptance criteria mainly include ALARP principle, F-N curve, risk matrix and so on. There are also some standard values to measure risk, such as AIR value and PLL value. This paper mainly introduces the research method of ALARP principle and F-N curve combined with standard value.

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### 3.1. ALARP Principle

ALARP principle is also known as the minimum reasonable feasible principle. The ALARP principle is explicitly designated by the UK Health and Safety Committee as the criteria for risk management and decision making, and is the standard framework for the establishment of acceptable risk. [7] The meaning of THE ALARP principle is that any industrial activity has risks, which cannot be completely eliminated through preventive measures. In addition, the lower the risk level of the system is, the more difficult it is to further reduce the risk, and the cost tends to rise exponentially. Therefore, a balance must be made between the risk level of the system and the cost.

ALARP principle is a basic criterion in the current development stage of RAC, which is the theoretical basis of various methods and models. Because ALARP principle is widely applied to personal, social and environmental risk acceptance criteria, it has been widely used in risk management and risk assessment in various fields.

### 3.2. AIR Value

Personal risk [8] refers to the frequency of death caused by specific hazards for people who live in a specific place for a long time without taking any protective measures, which is the smallest unit of social risk. The acceptable risk standard for general individuals can be expressed by AIR value method [9], average mortality method and annual death risk method, etc. Zhang shu et al. [10] used the average individual value at risk (AIR) method to study the individual mortality rate of coal mines from 2003 to 2007 and from 2008 to 2012 with a cycle of 5a, so as to determine the reference range of acceptable risk standard for coal mines from 2013 to 2017. According to the National People's Congress changing cycle (5A) as a cycle, the author uses AIR value method to calculate the standard value of individual acceptable risk in coal mines. AIR refers to the number of deaths a person dies doing their job in a year, reflecting the average individual risk, which can be derived from the AFR.

$$I = F/\phi \tag{1}$$

Where: I is the average individual risk of the studied industry, namely AIR value; F is the mortality rate of employees in the studied industry, namely, the AFR value, $F = N/T$ , N and T are the number of deaths and total number of employees respectively; ∅ is the proportion of the annual working time of the practitioner as a percentage of the total time, $\phi = t_w/t_a$ ,tw is the actual working hours of employees every year, ta is the total time of a year, calculated according to 365 days, 52 weeks and 8h of employees' daily work, $t_w$ =2080h and $t_a$ =8760h. The median of the whole set of data is taken as Rr, the acceptable risk reference value for individuals. However, in collective decisions in daily life, more than half of those who approve can pass the decision, indicating that 1/2 can be used as the dividing line between quality and quantity. Based on this, 0.5 is taken as the floating range, and the base value is fluctuated by 0.5, so as to obtain a risk area. Based on this, the upper and lower limits of acceptable personal risk standards are obtained.

### 3.3. PLL Value

Potential Loss of Life (PLL) refers to the frequency that all personnel within a certain range may suffer certain risks in a specific period. For a particular activity (e.g., a ship), the acceptable average potential loss of life ($PLL_A$) can be based on the economic value (EV) of the activity. This provision states that the bulk of the total occupational risk should be allocated to different activities as a proportion of the GROSS national product and that significant deviations should be considered sufficient grounds for review. Similar standards should be developed for

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202111_7(11).0034

transport activities. For activities and industries of low social importance, society may be reluctant to accept a higher risk of accidental death. Only minor risks should be accepted for activities and industries that are not significant and contribute little to the production of services. The ultimate solution is to eliminate the risk of death by eliminating the activity itself. In this way, a security budget can be established. Low economic importance equals low $PLL_A$. $PLL_A$ calculation can be divided into two types: (2) for occupational accidents, such as the risk assessment value of liquefied gas vessels; (3) for transport-related accidents, such as passenger ships, the risk assessment value is:

$$PLL_A = q \times EV \tag{2}$$

$$PLL_A = r \times EV \tag{3}$$

In the case of occupational accidents, q is the average death rate in terms of gross national product. For transport-related accidents such as passenger ships, a similar composite indicator r is defined. Where, the algorithm of q and r is:

$$q = \frac{\text{Number of occupational fatalities}}{\text{GNP}} \tag{4}$$

$$r = \frac{\text{Number of fatalities due to transportation}}{\text{Contrubution to GNP from transportation}} \tag{5}$$

### 3.4. FN Curve

Based on the ALARP principle, F-N curve is divided into three areas: negligible risk area, tolerable risk area and intolerable risk area. On the basis of only zoning, quantitative calculation and analysis are carried out to determine the dividing line of the three zones. F-n curve calls the line dividing negligible risk area and tolerable risk area as the negligible risk line. The offline side area for negligible risk, said the accident losses in this area and can be ignored, will be able to tolerate risk area and intolerable risk area dividing line known as the intolerable risk line, the line at the top of the area for the intolerable risk, said the accident losses in this area and can't accept, must take measures for its improvement, To reduce the loss below the intolerable risk line, the tolerable risk zone is between the negligible risk line and the intolerable risk line. It is necessary to measure the loss according to the specific accident and invest some money to reduce the risk.

3.4.1 Application of FN curve

At present, there are three methods to establish F-N curve, the core idea of which is to determine the probability distribution and draw the curve:

Analyze existing standards of other research objects and make reasonable changes according to the characteristics of the industry;

Using historical data to construct a probability model to calculate and evaluate the probability of its occurrence;

The formula of F-N curve was obtained by PLL value fitting. The following describes the research methods of risk acceptability criteria in various fields.

At present, the f-N curve is used to study the risk assessment of pressure pipelines, coal mines, DAMS and ships. Among them, the theoretical expressions of F-n curve are general formulas such as (6) and (7) :

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202111_7(11).0034

Where, the theoretical expression of F-n is:

$$P_f(x) = 1 - F_N(x) = \int_x^{\infty} f_N(x)dx \tag{6}$$

$$F = \sum_{N=1}^{N} f(N) \tag{7}$$

Formula (5): Pf(x) is the probability that the annual number of deaths is greater than N; FN(x) is the probability distribution function of annual death number N;

Formula (7): F is the cumulative frequency of accidents with annual death number greater than N; f(N) is the frequency of accidents with N deaths per year.

At present, many countries use Formula (8) to determine the socially acceptable standard of FN curve:

$$1 - F_N(x) \le C/x^n \tag{8}$$

Combining equations (5), (6) and (7), we can get (8):

$$F \le C/x^n \tag{9}$$

C is a constant, representing the intercept of the FN limit line, and N represents the slope of the FN limit line.

Yang Yanpeng et al.[11], in the study of the risk acceptance standard of pressure pipelines, counted the casualty data of China over the years, analyzed it with the method of linear regression, and determined the acceptable criterion of social risk (SR) of pressure pipelines in China by combining F-N curve and ALARP principle. After the statistical data, the accumulated frequency of accidents representing I or more deaths within 1a was tabulated by year, and the equal sign was taken from formula (9) and deformed to obtain: $\mathrm{Fx}^{\mathrm{n}} = C$

Take the logarithm of both sides of this equation and you get (10):

$$\lg F = -n \lg x + C \tag{10}$$

Logarithms were taken of the number of deaths and the cumulative frequency of deaths obtained by statistical calculation, and linear regression analysis was conducted to obtain n and C values, and then the FN curve was obtained. Zhijun wu [12] in Marine traffic risk acceptance criteria in using this method, the FN curve of the Marine traffic risk assessment standards, according to the ship's personnel all death is not can be accepted by the society, which in addition to the passenger of the rest of the small and medium-sized and large ship's crew of the ship's number are not exceed 30 people, and thus determine the consequences as line for 30 people.

Meanwhile, the next step in obtaining FN curve is to apply the accident classification to the obtained FN curve [13], as shown in Figure 1. Zhang Fengli [14] drew a curve of oil spill frequency in the study of tanker oil spill with the oil spill volume as the horizontal axis and the cumulative oil spill frequency as the vertical axis. Meanwhile, FT curve was used as a tangent

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202111_7(11).0034

line with a slope of -1. The tangent line was an intolerable risk line, and the intolerable risk line was moved down by two orders of magnitude, namely, the negligible risk line.

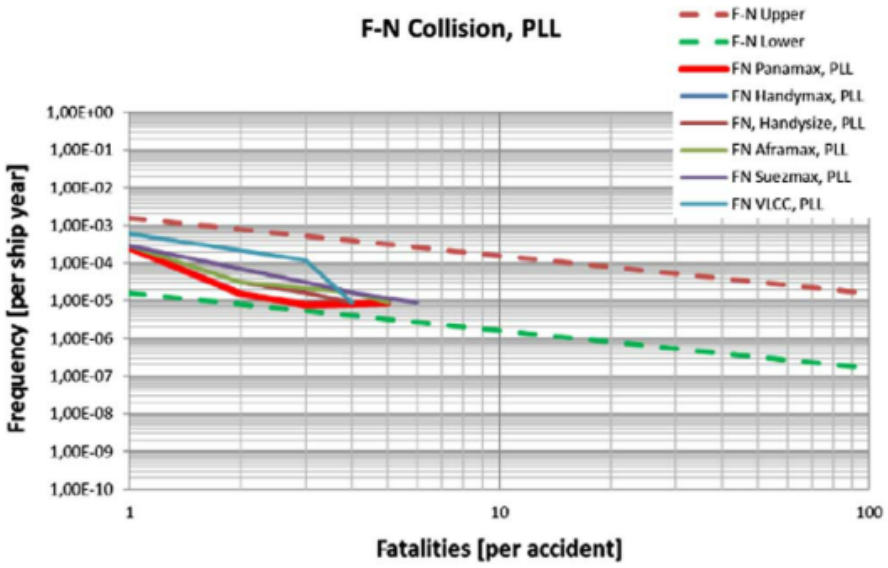


**Figure 1.** Cumulative death frequency curve of collision

In the study of the social risk acceptance standard of coal mines, Shu et al. determined the social acceptable risk standard of coal mines for reference through the FN curve. N is usually 1 or 2. When n = 1, the risk is called neutral risk, and the slope of its limit line is -1. When n = 2, the risk is called aversion risk, and the slope of its limit line is -2. N is evaluated according to the safety situation of the research object, for example, n=2 in the author's coal mine research.

The meaning of each point on the FN curve can be expressed as follows:

$$S_n = a_1(1-q^n)/(1-q) \tag{11}$$

Where $S_n$ is the accumulated frequency of accidents; $a_1$ is the first term of the geometric sequence; q is the common ratio of geometric series; n is the total number of people. When calculating the socially acceptable risk standard, $a_1$=q. Since q ≤1 and the order of magnitude of q is small in the calculation process, $S_n$=q. The starting point of the risk line of the socially acceptable risk standard should be the acceptable risk standard value of individuals, that is, C should be the acceptable risk standard value of individuals. Formula (9) is adopted to calculate, and C value is the acceptable risk standard for individuals in coal mines. The intolerable risk line is that the value of C is 1-2 orders of magnitude less than the standard acceptable risk value of individuals. The intolerable risk line of FN curve can be obtained according to Formula (9) and the reference risk value of individuals mentioned above.

3.4.2 Fitting method of FN curve and PLL

In the decision parameters of risk acceptance standard submitted by Norway [15], it is mentioned that after the $PLL_A$ parameters obtained, FN curve with inclination of b is fitted into the $PLL_A$ obtained, and the fitting method is shown in Equation (12).

$$PLL_A = \sum_{N=1}^{N_u} N f_N = F_1\left(\frac{1}{N_u^{b-1}} + \sum_{N=1}^{N_u-1} \frac{(N+1)^b - N^b}{N^{b-1}(N+1)^b}\right) \tag{12}$$

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$N_u$ is the upper limit of the number of deaths that may occur in an accident. For a ship, $N_u$ is the maximum number of crew and passengers. FN is the frequency of accidents involving N deaths; $F_1$ is the frequency of accidents involving one or more deaths. b =1, which can be simplified as:

$$\mathrm{PLL_A}=F_1(1+\sum_{N=1}^{N_u-1}\frac{1}{(N+1)})=F_1\sum_{N=1}^{N_u}\frac{1}{N} \tag{13}$$

And there is Equation (14):

$$F_1=PLL_A\Big/\sum_{N=1}^{N_u}\frac{1}{N} \tag{14}$$

By means of fitting, the accumulative frequency of the standard accident death number of F-N curve test is obtained.

### 3.5. Risk Matrix Method

Because quantified risk is often limited by imperfect data collection or technically impossible to accurately estimate, the quantified data has great uncertainty, and it takes much time and energy to implement it. Therefore, relative risk is a feasible method, and risk matrix is one of them. Risk matrix adopts relative methods to determine the two major variables of risk (probability estimation and consequences) and roughly divides them into several different grades.

## 4. SUMMARY AND PROSPECT OF RISK ACCEPTANCE CRITERIA

Risk acceptance criteria for different fields, according to different production characteristics, production environment, there are different suitable research methods and theories and final standards. Because of the interdisciplinary characteristics of risk analysis technology, there are still many problems in the interpenetration of new technologies between disciplines. In the basic research, methods and models are competing in the field of research. The conclusions and prospects of this paper are as follows: This paper introduces the definition and classification of risk standards, and summarizes the risk standard formulation method of F-N curve, which is convenient for the formulation of risk standards, and the above method can be applied to the formulation of risk standards in many fields. In the formulation of acceptable risk standards, the standard model or method developed needs to be analyzed by examples and tested to achieve accuracy and scientificity. Risk acceptance criteria are constantly changing with the development of various aspects of the country. With the continuous progress of science and technology, people's risk acceptance is expected to gradually increase, so that the risk acceptance standard is constantly strict. Therefore, the risk acceptance standard needs to be re-formulated every 5-10 years.

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