ANNUAL OF NAVIGATION 1/99

Galor Wiesław
Maritime University
Szczecin

THE ROLE OF RISK IN ESTIMATION OF SAFETY NAVIGATION

ABSTRACT

The paper presents the method of estimation of safety navigation. The proper criteria, measures and rate will need the estimation of safety navigation. These are very often expressed by risk. Four different definitions are used. The mostly used definition is a combination of accident probability with connection to its results. Probability of accident can be expressed in different manner. Three kinds of them are presented. Also the consequences of accident may be calculated in many aspects. There are necessary activities leading to efforts of unifying of these quantities.

INTRODUCTION

The main aim of navigation is leadership of ships in accordance with aim of their movement when required parameters of this process should be retained. Realisation of this aim depends on assurance of suitable level of ships safety during their manoeuvring in water area. Process of ships safe movement in water area is called a safe navigation. Its estimation is executed by means of notions of safety navigation. It may be qualified [Urbański, 1994] as set of states of technical, organisational, operating and exploitation conditions and set of recommendations, rules and procedures, which when used and during leaderships of ship navigation minimize possibility of events, whose consequence may be loss of life or health, material losses in consequence of damages, or losses of ship, load, port structures or pollution of environment.

Estimation of safety navigation (its state) will need the use of proper suitable criteria, measures and rates making its estimation possible. Criteria serve for base of estimation, while measures make its performance possible by means of rates. These criteria permit the qualification of damage, rising its possibility over limited values.

Many times definition of harm and accident are used in the same meaning in bibliography. Accident defined is a damage of device or machines causing the pause in their working or disturbances in operating. On the sea an accident is understood as harm carried out by ship or load in unhappy event.

The inequivalence in these definitions is apparent, because harm does not have to be consequence of unhappy event (in speculation of life and health), and for example shifts and damages of part of load result in defects of the fastening. On the other hand touching the channel dredge does not have to cause serious material harms.

For the estimations and the analysis of safety, especially quantitative one, the selection of quantities is needed which can be treated as measures of ones safety. Safety level is usually expressed by means of measures of risk.

Notion risks were in pasts defined in different ways. Basic definition was probability of appearing of losses. More precise definition of risk was given by Szopa [Szopa, 1998], which risk as possibility of losses appearing in result of undesirable events, which can come into being in definite fragment of system man – techniques – environment in definite period of time. One began also to use definition of risks as a combination of accident probability and its result, which one causes. At least four different definitions can be used [Savenije, 1998] for a quantitative approach:

1. risk = effect, result
2. risk = probability
3. risk = probability * result
4. risk = probability *(result) ^{n}

Definition 1 can be used at description of accident like disaster, for example loss of lives of large number of people, or of thousands tons of oil outflow from broken tankers. Definition 2 identifying risk with probability of accident is often useful. However, a result of accident is not here taken into account. This method can be useful to accident about not large results, e.g. entry on shallow without damages of ship. The third definition is mostly used as combination of accident probability with connection to its results. However, at such approach taken into account, there is only one kind of losses. Definition four can be used for very different results of accident, e.g. human life loss, ship damage and environmental pollution [Permanent, 1997]. Preparation of common degrees of these different results will need the proper analysis and estimations of their mutual weights. This will permit on transformation to common rate of losses.

Definitions 2 and 3 will be mostly used. The probability of accident is estimated in both cases.

PROBABILITY OF ACCIDENT

Probability of accident is expressed in different ways. Most often used are:

- frequency of events,
- probability of accident in one ship transit,
- overall probability of accident.

The kind of the used definition greatly depends on kind of the possessed information about the accident. Basing on given statistical data it is easy to operate frequency of events (accident).

It presents mostly number of events in a given period, for example the number of ships sunk in the year. More adequate measure is the rate of accident. It is expressed as a number of accident in relation to definite number of manoeuvres (transits of ships in fairway, entries to port, etc). This rate is qualified in relation to constant of manoeuvres number (10^3, 10^6), for example 17 of accidents on 1000 ships manoeuvres. Most precise quantity is the rate qualifying number of accidents in relation to definite number transits estimated for certain period of time (e.g. 1 year). This rate is often used and called as frequency of accident or probability of accident.

$$f_a = \frac{N_c}{N_V \cdot T} \tag{1}$$

where: f_a - frequency of accident,
N_c - number of accident,
N_V - number of transits,
T - period of time.

Probability of accident in one transit is connected with investigation of navigation process (manoeuvring) as a statistical process. This process is described by means of mathematical method using proper model of distribution. Such model permits on providing process by using of certain limited number of data. Parameters of such distribution permit to estimate probability of occurrence of definite events for a given level of confidence. For example acceptance of probability P = 0, 99 (99%) means that parameters of fairway became accepted in this manner, that probability of accident in one transit carries out P_A= 0, 01. However, it doesn't mean, that accident will take place once for 100 transits, or 10 ounces for 1000 passages. Probability of accident for definite number of transits or for long enough time (containing properly large number of transits) can be estimated by means of proper statistical distributions. They have special use, if accident takes place for relatively large number of transits. If accident takes place comparatively seldom in relation to number of events, as models statistical estimations of accident probability one can use recurrent models. Most often used are both: distributions geometrical and Poisson's distributions.

The first of them is found for probability of events (accidents) for single event [Galor, 1997].

$$P_A = 1 - (1 - p)N \tag{2}$$

where: P_A - overall probability of accident,
p - probability of accident in one transit,
N - number of ship to transit.

This distribution takes into account a number of accidents at definite possibilities (probability) of accident for single events (Fig. 1).

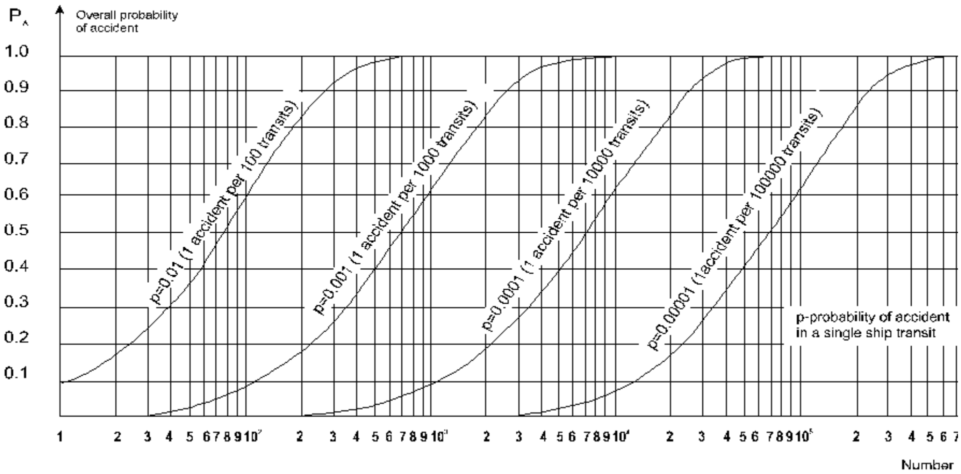

Fig. 1. Overall probability of accident for a number of transits

Fig. 1 presents the overall probability of a navigational accident as a function of accident probability in one transit for a given number of transits.

By analysing the graphs in Fig. 1 one can state that the total accident probability amounts to:

- P_A (0.63 for *N* ship transits equal to the number for which the probability of an accident in one transit corresponds to 1 accident (e.g. $p = 0.01$ corresponds to 1 accident out of 100 transits),
- P_A (0.95 is obtained with the number of transits three times higher than the number for which probability of an accident corresponds to 1 accident,
- P_A (0.99 is obtained with 4.5 times larger number of transits.

If the process is taken into account in function of time, it is more useful to use Poisson's distribution. Then probability of accident can be expressed as:

$$P_A(x = n) = \frac{\lambda^n}{n!} \cdot e^{-\lambda} \tag{3}$$

where: P_A - probability of accident,
λ - intensity of accidents,
n – number of accidents.

Such distribution permits to qualify probability of accident for definite number of accidents. Probability of *n* or more accident, is equal:

$$P_A(x > 0) = 1 - P_A(x = 0) = 1 - e^{-\lambda} \tag{4}$$

Then probability of the accident will not occur in definite period of time and can be written as:

$$P_A(x = 0) = e^{-\lambda} \tag{5}$$

This distribution permits the wide interpretation of results. One of most often used is estimation of accidents for accepted level of accident probability. For example, if desirable result should be probability of no accident at 95 % level, then:

$$P_A\,(x = 0) = e^{-\lambda} = 0,95 \tag{6}$$

Hence intensity of accidents is equal λ = 0,0513

On this base it is possible to define the rate of accidents as a period of time and the chance of one accident for examined period of time T. This is:

$$T_w = \frac{T}{\lambda} \tag{7}$$

where: T_w - period of time and the chance of one accident occurrence,
λ- intensity of accidents,
T - examined period of time.

Table 1 presents rate of events as a time period of the chance of one accident for intensities of accidents λ= 0, 0513.

Table 1. Time period of the chance of one accident

Intensity of accidents λ	examined period of time (years)	period of time the chance of accident (years)
0, 0513	5	100
0, 0513	10	200
0, 0513	25	500
0, 0513	50	1000

Having a number of ships transit in definite period of time, one can estimate the probability of accident (frequency) in one transit of ships in the found period of time.

$$p = \frac{\lambda}{I_R \cdot t} \tag{8}$$

where: P - probability of accident in one transit (frequency),
λ - intensity of accidents,
I_R - intensity of ship transits per year,
T - period of time.

For example if:

λ = 0, 0513,
I_R = 200 transits per year,
T = 25 years.

Probability of accident in one transit amount to p = $10.26 \cdot 10^{-6}$, which means 10.26 accidents per million transits of ships at found intensities of ships movement.

The presented considerations show, that probability of accident is expressed by means of different rates. It will be needed to know accepted quantities at investigation given values of accident probability.

RISK OF ACCIDENT

Risk of accident is combination of accident probability and its results (consequence) [4].

Initially the following definition had been used:

$$R = f \cdot N_C \tag{9}$$

where: R – risk,

f - frequency of accidents,

N_C - number of loss of life.

On the Baltic Sea in the period of last years was very famous the sinking of passenger - ferries m/f Heweliusz (55 victims) and m/f Estonia (852 victims). It was very famous accidents during last years on the Baltic Sea. Risk of loss of life for this type of accidents is, however, considerably less, than in other kinds of transportation. For car transport this risk is about 1000 greater ounces. Most of navigational accident does not finish at loss of life, however, their consequences are different. Hence the universal definition of navigational risk can be expressed as:

$$R_N = P_A \cdot S \tag{10}$$

where: R_N - navigational risk,

P_A - probability of accident,

S - accident consequences.

Methods of qualifying probabilities of accident are represented in preceding subsection. Consequences of accident can be examined in different aspects. Most often are:

- losses of life,
- economic,
- physical,
- costs of insurance,
- pollution of environment,
- other (psychological, sociological, cultural – historic).

Consequences of every accident can be of different dimension. Bringing all the results to one dimension is very difficult. This will need of suitable transformation. Being able to step out simultaneously damage of ship, load, port structures, loss of life and health, pollution of environment and loss of potential profit in consequence the limitations of the work of port or ships is difficult to be estimated.

Effort of universal estimations of results is an economic method. Independently from kind of losses, every of them can have fixed price by means of proper sums of money. However, it has in some cases large defects. Loss of life can fix the price by means of sums of insurance in case of death. However, from one side this sum depends on quantities of paid collections, companionships insurance company, etc, while on the other hand this sum does not make up psychical losses of the nearest family, or sociological ones given of a group of society.

Similarly accident whose result is pollution of environment is difficult to estimate economic values. Overflow of oils from broken ship produces so various consequences for environment, that its estimation by means of one criterion is very difficult.

Thus generally the results of navigational accident can be examined in the aspect of the event – disaster. The disaster produces difficult results to be described. Because most of accidents include events over limited results, their description is more easy to be done.

On restricted waters the accident results from account of movement of this vessels in relation to water area. Its result can be a ship bottom strike (entry on shallow) or coast elements (port structures), strike in floating objects not moving (moored ships, dredges, etc) and collision of two moving ships.

Measure of results of this accident in such cases can be maximum energy of strike of ship in these objects [3]. Effects of such events can be expressed as:

$$S = \frac{E_{(t_i)}}{E_{\max}} \tag{11}$$

where: S – effect of accident,

$E_{(ti)}$ - maximum energy of ship in moment of her contact with other element,

E_{max} - permitted energy not causing damages.

If value S is included in interval $S \in (0, 1)$, essential losses do not exist. This state can be called as hazard state that potentially is able to lead to losses. Instead when $S > 1$ to damage of ship hull or remaining elements in which ship struck follows.

Such a model of accident results became used to estimations the navigational risk of manoeuvring ship in restricted water area.

$$R = P_A \cdot I_R \cdot S \tag{12}$$

where: R – risk,

P_A - probability of accident,

I_R – year average intensity of given manoeuvre executing,

S - relative results of accident.

This is a very important method of risk estimation by means of physical estimations of accident results. However, this method of risk estimation does not take into account the additional results of accident, connected with transported cargo. These results can be various in dependencies of type of transported cargo (toxic, explosive, polluting, combustible, corrosive and others). The same ship participating in accident in the same conditions in water area, once for example with mass – cargo (coal), secondly from liquid (raw oil), in cases of hull damages can cause considerably worst results of accident in the second case [Galor, 1998]. Thus the necessity of taking into account a kind of transported cargo in regard with accident consequences when risk estimation will be made.

One of such methods is partition of ships transporting definite cargo in categories about different degree of hazard in case of accident. Here are cargoes creating corresponding level of hazard:

- low (bulk carriers, container ships, passenger, general cargo ships, flammable cargo, etc),
- average (tankers transporting raw oil, oil products with low flammable degree, edible oil, etc),
- large (ships transporting gas, LPG, LNG, chemical cargo, etc).

This partition can be more detailed basing on international code of dangerous materials. Using such partition, results of accident one can express in the form of weight taking into account type of transported cargo (for ships comparable sizes). Then risk can be expressed as:

$$R = P_A \cdot S_j \cdot w \qquad (13)$$

where: P_A - probability of accident,
S_j - individual results of accident,
w - weight connected with type of transported cargo.

Individual results of accident (weight w=1) can express results of ship accident with low cargo hazard (e.g. with mass – cargo type coal, ore, etc). For every other type of load suitable weight will become assigned. Accepting for averages degree hazard of cargo the value of weight for example w=10, risks for both ships about comparable quantities during manoeuvring in a given water area will be different.

When keeping the same level of safety for both cases, the risks can be described as:

$$R = P_{A1} \cdot S_1 = P_{A2} \cdot S_2 \qquad (14)$$

where: P_{A1}, S_1 - probability of accident and results at low hazard cargo,
P_{A2}, S_2 - probability of accident and results at averages degree hazard cargo.
At accepted weights ($w_1 = 1$, $w_2 = 10$), it can be written as:

$$P_{A2} = P_{A1} / w_2 = P_{A1} / 10 \qquad (15)$$

It results that probability of ship accident with averages degree hazard cargo should be ten times less than for low degree hazard cargo.

Maintenance of this condition will need series of proper activities. One of them can be properly large assurance of accessible area of manoeuvring.

The presented method of constant risks can be developed by improvement of methods of accident results estimation and weight of its results.

SUMMARY

The analysis of safe navigation will need the acceptances of definite criteria that will permit its expression in the form of suitable measure and rates. The observed world tendencies are various and will need suitable studies in this respect. Most often used methods of its estimation are methods based on probabilistic models of event description of such navigational accident. However, the potential results of such accident are connected, in consequence these quantities obtain the navigational risk. Both probability of accident, occurrence and its results are expressed in different form and different measures. There are necessary indispensable activities leading to efforts of unifying these quantities. The appearing attempts of present safety navigation as a defined rate indicate necessity of carrying on the study in this field of science.

REFERENCES

1. Galor W. Estimation of navigational risk of ship movement in restricted waters. Proc. of IV Conference Shipbuilding and Ocean Technology, Międzyzdroje, 1998 (in Polish).
2. Galor W. The Safety of Navigation of Ship Movement in a Channel. Archives of Transport Polish Academy of Science, vol. 3, issue 3-4, Warszawa, 1997.
3. Gucma S. A Risk of Manoeuvring the Vessel Entering the Port, 29th PIANC Navigation Congress, Den Haag, 6-11 September, 1998.
4. Permanent International Association of Navigation Congresses PIANC, Approach Channel. A Guide for Design. PIANC Bulletin No. 95, Supplement, Brussels, 1997.
5. Savenije A. C. Safety Criteria for Approach Channels. Ministry of Transport, Public Works and Water Management, Transport Research Centre, Paper No: 98-HKP-01, Rotterdam, 1998.
6. Szopa T. Risk and hazard. Proc. of IV Conference Shipbuilding and Ocean Technology, Międzyzdroje, 1998 (in Polish).
7. Urbański J. Effort of specify of range meaning idea respecting of safety at sea and navigational safety. Proc. IX Conference The role of navigation in protection of human activity at sea'. Naval Academy, Gdynia, 1994 (in Polish).