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Bąk Andrzej

Gucma Lucjan
Maritime University of Szczecin, Szczecin, Poland

Risk assessment of ships collision with moored ships by statistical method

Keywords

safety of navigation, risk assessment of collision with moored ships

Abstract

The paper presents simplify statistical method of risk assessment of collision with moored ships. The model is based on statistical – historical data and could be used for designing the places of dangerous cargo discharge or safety analysis of existing ones.

1. Introduction

The problems of quays location where loading and discharging of dangerous cargo is planned should be considered as serious due to possible consequences, especially when these locations coexist with high ships traffic or with the passenger ship traffic. To find safety of such locations the risk assessment methods should be applied. Sometimes due to reduced cost of researches there is no possibility to use sophisticated methods such as real time manoeuvring simulation methods. The solution could be application of simpler statistical methods such as the one presented in this study.

2. Risk assessment in marine traffic engineering

The procedure of the risk management is multi-stage rational method, targeting to increase the shipping safety by the protection of life, health of people, environments and properties [6]. The procedure consist of the risk analysis (estimation), the assessment of the risk (evaluating), taking decision about risk acceptability and its temporary control (risk monitoring). In analyses related to the safety of navigation, like in the most of engineer applications, the risk R is defined as the scalar value, describing possibility of the losses in the determined time unit, and expressed as the product of the probability of the accident and its losses. The most frequent definition of risk R is as follows:

$$R = PC \tag{1}$$

where:
P – measure of uncertainty,
C – measure of accident consequences.

Additionally, the definition could be supplemented with relative frequency of performing the given activity (for example: ship manoeuvre). If we assume that an accident and its consequences are independent events, navigational risk can be presented as following product:

$$R = N_y P_m C \tag{2}$$

where:
N_y – yearly intensity (frequency) of performing a given manoeuvre,
P_m – probability of accident in given ship manoeuvre;
C – accident consequences.

In case of the occurrence of different levels of losses, the risks are summed and expressed as follows [1] and :

$$R = \sum_{i=1}^{n} P_i C_i \tag{3}$$

where:
P_i – probability of the appearance of the *i*-tch accident kind in time unit (i = 1, 2, ..., n),
C_i – consequences of *i*-tch accident kind in time unit,
n − the number of accidents kinds.

Grouping the risk ascending in respect of the probability, one can determine the vector of risk as proposed by Kaplan and Garrick [5]:

$$R = [P_1C_1, P_2C_2, ..P_iC_i] \tag{4}$$

The above formula (4) is not contradictory with the previously presented. The risk defined in this way, after the conversion to the continuous function, can be presented as so called "risk curve" (*Figure 1*). In this case risk can be defined as area under curve:

$$R = \int_{\min C}^{\max C} P(C)dC \tag{5}$$

Risk reduction could be realised either by minimising the consequences or probability of its occurrence as shown in *Figure 1*. by two arrows.

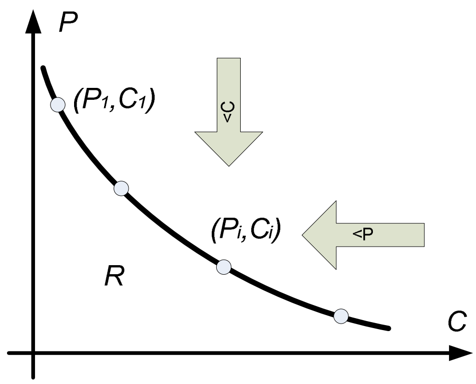

Figure 1. The risk curve. Two ways of risk mitigation

3. Risk acceptance criteria based on maximum rate of serious accidents

In marine traffic engineering systems there is usually lack of guidelines concerning the acceptable risk. In these systems the accidents with fatalities are usually rare. The criteria values are determined by applying the probabilistic methods based on the number of accidents [2], [7].
The basic criterion of navigation safety is the probability that a ship passage ends up with an accident P_A or the probability that the passage will be accident free (1- P_A). With a simplification concerning the independent character of accident-affecting factors and countermeasures, we propose to determine the probability of ship's successful passage as:

$$1 - P_A = (1 - P_H)(1 - P_T)(1 - P_N) \tag{6}$$

where:
P_H – probability of accident due to human error,
P_T – probability of accident due to technical failure,
P_N – probability that navigational conditions will be the reason of accident.

In a more general case we should take into account N passages of given ship. Then the probability criterion is proposed to be the fact that in N ship passages there will occur n accidents $P(X = n)$, with the adopted accident probability in one passage being P_A. Furthermore, if we assume that accidents in particular passages are independent of each other, and that: $P_{A1} = P_{A2} = ... = P_{An} = P_A << 1$, the probability of n accidents can be assessed by Poisson distribution in following form:

$$P(X = n) = \frac{N{P_A}^n e^{-NP_A}}{n!} \tag{7}$$

where:
$NP_A = \lambda$ – intensity, expected number of an accident probability in N passages.

From the above relation the probability of no accident in N passages could be determined, (i.e. an safety indicator of marine traffic engineering system) as:

$$P(X = 0) = e^{-NP_A} \tag{8}$$

and an accident rate indicator, expressing the probability of at least one accident in N passages as:

$$P(X \geq 0) = 1 - e^{-NP_A} \tag{9}$$

It is typical to express safety affecting indicators depending on ship passage time and taking into account the intensity of ship accident stream intensity. Denoting the accident stream intensity in a time unit as λ, we can assume that:

$$m_{An} = NP_A = \lambda t_c \tag{10}$$

where t_c is total time when N ship passages occur.

So called "Dutch criteria" of navigation safety on tidal waterways (restricted waters) such as Rotterdam

Port area allow that criteria probability (p_c) of one accident during t_c=25 years of waterway operation could be equal or less than 0.1 (10%). Based on Poisson distribution we calculate that 25 years intensity (λ_{25y}) of accidents is equal to:

$$\lambda_{25y} = t_c \lambda_{1y} = -\ln(1 - p_c) = -\ln(0.9)$$
$$= 0.105 \text{ [accident/25 years]} \quad (11)$$

which lead to criteria value of not more than one accident in 237 years, which translates into 0.004 accident (grounding) per year. On the other hand, British criteria on deep water routes accept maximum 0.001 accident (grounding) in a year [7].

The application of risk assessment methods relies on the definition of the permissible number of serious accidents or probabilities of serious accident occurrence. This number could be calculated with knowledge of serious (p_s) to all accidents (p_a) ratio:

$$r_{s/a} = p_s / p_a \quad (12)$$

The above $r_{s/a}$ is often called "Heinrich ratio" and for maritime transportation is assumed usually as 0.1 [3] (i.e. 10% of chance that given accident will end with serious consequences).

In case of presented simplify approach to maritime traffic engineering systems it is usually assumed that consequences are set of only two possible elements:

$$C = \{C_s, C_m\} \quad (13)$$

where:
C_s – consequence of serious accident,
C_m – consequence of minor accident.

The mitigation of minor accident does not require special rescue operations, and quite often incidents are not reported to maritime administration or even the ship owner. To eliminate consequences of serious accident, on the other hand, a rescue or salvage operation has to be organized.

Waterways are generally designed for a period of 50 to 100 years of operation, while ships are designed to serve for 15-30 years. However, the following facts should be considered:

- in the course of 50-100 year operation of a waterway it is modernized a few times; such modernization results from, among other reasons, the introduction of more advanced navigational systems, manoeuvring methods and ships;
- each new generation of ships (after 15 years) is better in terms of manoeuvring ability, navigational systems, technical reliability etc.

With the above facts taken into account, we may claim that safety requirements, important as they are, should not be excessive. Therefore, the following navigational safety criteria may apply ships in restricted waters:

- tidal areas the maximum of 0.004 accident per year or the maximum 0.04 total number of incidents and accidents;
- non-tidal areas the maximum of 0.007 accident per year or maximum 0.07 of total number of incidents and accidents.

If we neglect minor accidents the risk of serious accident then can be expressed as:

$$R = PC_s r_{s/a} \quad (14)$$

The risk acceptance criteria could be further defined as:

$$R \le R_{acc} \quad (15)$$

4. Statistical method of risk assessment of collision with moored ships

In case of risk assessment of collision with moored ships the simplest approach is to use statistical (historical) methods with some additional assumptions made by expert opinion. Typical scenario of collision is presented in *Figure 2*. The reasons of such accident could be [4]:

1. human error (communication problems, mistake etc),
2. technical error (black out, rudder blocking, tug rope broken etc.),
3. weather (visibility, wind gust etc).

In presented statistical methods the databases usually doesn't describe properly the accident causes and all accidents are analysed together.

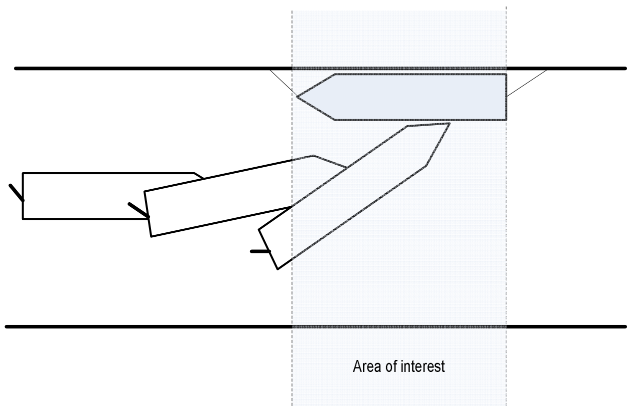

Figure 1. Example scenario of collision due to technical error (rudder is blocked in port position)

The risk of serious collision accident with moored ship can be assessed as (indexes are taken from *Table 1*):

$$R = r_{s/a}(P_6 + P_7)P_{14}P_{15}P_{16}P_{17}N_y$$
$$= r_{s/a}P_8P_{14}P_{15}P_{16}P_{17}N_y \qquad (16)$$

where:
P_6 – probability of ship accident with tug,
P_7 – probability of ship accident with moored ship,
P_8 – based sum probability of accident in one manoeuvre (obtained from historical data),
P_{11} – fraction of time when ship is near moored ship to all time of manoeuvre,
P_{12} – probability that the ship and tugs does not countermeasure the accident,
P_{13} – probability that ship will be drifting towards given moored ship (usually 0.5),
P_{13} – probability that the ship is moored (quay occupation) determined by historical data,
N_y – intensity of ships per year.

4.1. Case study

The case study cover the assessment the probability of collision of ships passing to Przemysłowy Canal with chemical tankers moored to SWFiL quay in Szczecin port (*Figure 3*). The practical need of such assessment arisen due to controversial situation of necessity of stopping the discharging the chemical tankers during such passage which is not easy from the technological point of view.
The risk was assessed assuming that during approach manoeuvres to Przemysłowy Canal ship collides with tanker moored at SWFiL quay due to human or technical error. The risk was determined with statistical techniques basing on the number of similar events in the region of ports Szczecin and Świnoujście accepting some additional assumptions related to the time spending in vicinity of SWFiL quay. The based model is presented in previous section.

To find the basic historical probability of accident with moored ships two possible accidents were taken into consideration:
1. accident with tug during towing (with yearly intensity = λ_1);
2. striking of the underway ship into the moored ship (with yearly intensity = λ_2).

It was assumed that both of accidents could be the reason of collision with moored chemical tanker.
To find the probability of critical event accident database of Szczecin and Świnoujście ports area have been analysed. The 17 years (1991-2008) gave mean intensities of accidents of interest as follows: $\lambda_1 = 0.71$ and $\lambda_2 = 0.47$ accident per year (*Figure 4*) and the sum of those events equals 1.18 accident/year. The accidents of those two categories during 17 years of investigations are presented in *Figure 4*.

In *Table 1* it is presented all values adopted for risks assessment and the calculated all accidents and serious accident risk per year. These values were compared to previously defined criteria.

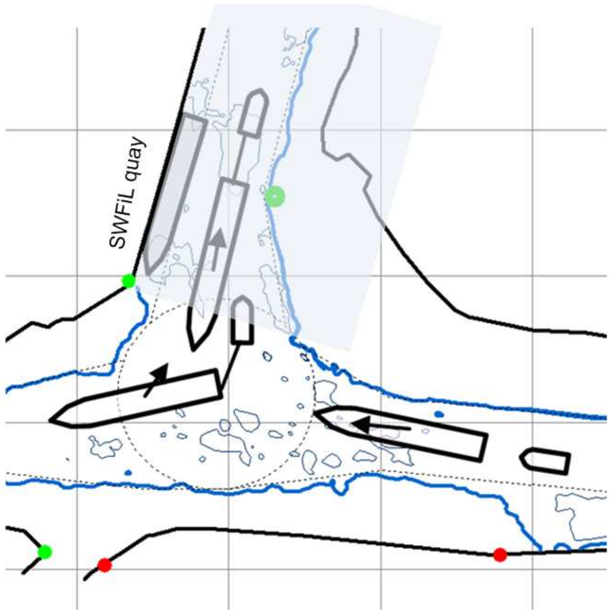

Figure 3. The area of interest. The manoeuvre of turning with tug near the SWFiL Quay in Szczecin where chemical tanker is moored

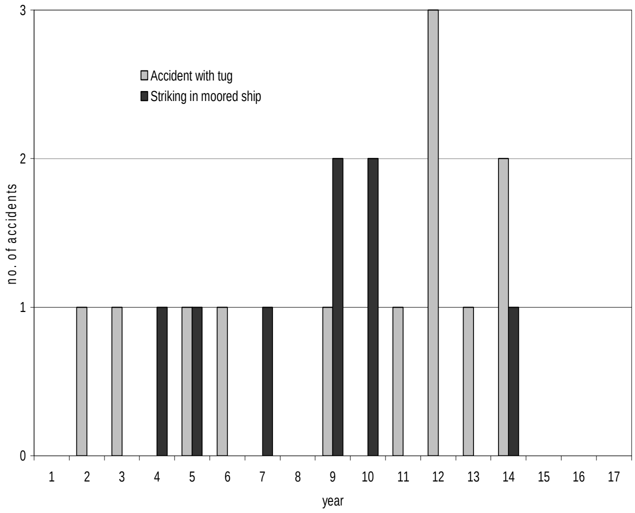

Figure 4. Accidents with tugs and collisions with moored ships in Świnoujście and Szczecin ports for analysed 17 years (1991-2008)

Table 1. The valuation of the risk of the collision of the ship passing on the Przemysłowy Canal with the ship moored to the SWFiL Quay

Lp.	Name	Value	Unit
1	Mean intensity of accidents with moored ships	0.47	acc./year
2	Mean intensity of accidents with tugs	0.71	acc./year
3	Mean yearly intensity of ships	8000	ships/year
4	Probability that ship will use tug service in port	0.3	
5	Number of ships with tugs	2400	ships/year
6	Probability of accident with tug in one maneuver	0.0002958	
7	Probability of collision with moored ship in one maneuver	0.0000587	
8	Probability of collision with moored ship and/or with tug in one maneuver	0.0003545	
9	Speed of ships during passage	1	m/s
10	Distance during approach to Przemysłowy Canal	1000	m
11	Mean time of approaching to Przemysłowy Canal	1000	s
12	Length of occupied quay (SWFiL) two tankers	250	m
13	Time of sailing in the vicinity of SWFiL	250	s
14	The time relation of ships sailing near SWFiL to all passage	0.25	
15	Probability that ship or tugs will not countermeasure the accident	0.8	
16	Probability that ship will be drifted towards SWFiL	0.8	
17	Probability that SWFiL quay is occupied by tankers	0.5	
18	Yearly intensity of ships to Przemysłowy Canal (2 per week)	209	ships/year
19	Final probability of ship collision with tanker on SWFiL quay	0.0059164	
20	Years between accidents	169	years
21	Relation of serious to all accidents (10%)	0.1	
22	Risk of serious accident per year	0.0005916	1/year
23	Years between serious accident	1690	years
24	Acceptable risk of serious accident	0.007	1/year
25	If risk if less then acceptable?	YES	
26	Safety factor (R_{acc}/R)	12	

5. Conclusion

Risk assessment is procedure which should be applied for decision making in serious navigation problems especially those involving potentially severe consequences. During risk analysis all possible hazards should be considered by hazard analysis.

Presented simplified model of risk analysis of ship collision with moored tanker could be used in case when statistical data of previous such events are available. The achieved results show that risk is smaller than acceptable and ships could pass to Przemysłowy Canal without restrictions.

In case when the risk would be higher than acceptable some additional safety measures should be proposed to reduce the risk such as:

1. additional marking navigational,
2. the additional tug service,
3. special operation procedures.

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