Assessment of Navigational Safety in Vessel Traffic in an Open Area

Z. Pietrzykowski
Maritime University of Szczecin, Poland

ABSTRACT: The assessment of a navigational situation is of major importance for safe vessel conduct as well as countermeasures and reduction of threats resulting from undesired events. These events include, among others, technical failures and human errors. To describe cause and effect relationships fault tree and event tree analyses are used. An algorithm has been presented for the determination of vessel collision probability in an open area, based on the methods mentioned.

1 INTRODUCTION

The level of navigational safety depends on a variety of factors: the present navigational situation, correct functioning of technical equipment and systems, and navigators' knowledge, experience and skills. The probability of ships' collision is one of the indicators of navigational safety level. The determination of this probability makes up a basis for collision risk determination and risk management.

The fault tree method is one of the most frequently used methods of system analysis. This analysis has a deductive character and focuses on a specified undesired event (usually a failure or inoperability of a system), and its aim is to indicate possible ways for a desired situation to take place. The fault tree is a logical scheme showing the manner in which a fault or system inoperability may be caused by other events. The development and analysis of a fault tree for the process of vessel traffic are based on information on the process, equipment and human factor. The main stages of the FTA are:

- describing the system for FTA purposes and setting the system limits,
- identification of threats (risks),
- error tree construction,
- qualitative and quantitative analysis of the error tree.

The above method was used for the assessment of a navigational situation in an open sea area – the determination of ships' collision probability.

2 ASSESSMENT OF NAVIGATIONAL SAFETY - ASSUMPTIONS

While constructing an algorithm for the determination of ship collision probability the following assumptions were made:

1 The examined area for which the ship collision probability is to be determined is an open sea area.
2 An encounter situation involving several ships is considered and analyzed by decomposing it into encounters of two ships.
3 Ship encounter situations are described by the parameters of ship status vectors (position, course, speed, size, manoeuvring characteristics).
4 Ship's operational states are considered, such as rudder or main engine failures, and a blackout.

5 Hydrological and meteorological conditions are taken into account in the algorithm.

6 The algorithm accounts for the human factor involved into the decision making process of ship conduct as well as navigators' errors that may result in a ship collision.

7 Cause-and-effect relations of ship collisions are described by methods of fault tree and event tree.

8 Cause-and-effect relations of ship collisions implemented in the algorithm enable indicating possible areas of risk reduction.

9 Events that may bring about ships' collision are described with the probability of their occurrence.

10 The effect of algorithm operation is a determined value of collision probability of two encountering ships.

3 GENERAL CHARACTERISTIC OF THE ALGORITHM

The algorithm of determining the probability of ship collision in an open sea area is based on probabilistic methods of risk analysis and assessment. Fault trees and event trees of ship collisions in an open sea area have been developed.

While constructing a fault tree model, the cause-and-effect relationships for ship collision events were analyzed. On this basis a model of ship collision event tree was developed, presenting the influence of basic failure components on the effect, i.e. ships' collision.

Both external and internal events were taken into account, as well as operating states that might lead to a collision, such as equipment failures, human errors (human factor), the environment. The considerations herein concern the technical and procedural solutions in use, aimed at an enhancement of the reliability of system elements and the whole human-ship-environment system.

A model of ships' encounter was built (Fig. 1),

taking into account navigators' decision processes (Fig. 2), aimed at a solution of collision situations. Much attention was paid to the human factor and errors done by humans, errors that might lead to ships collision.
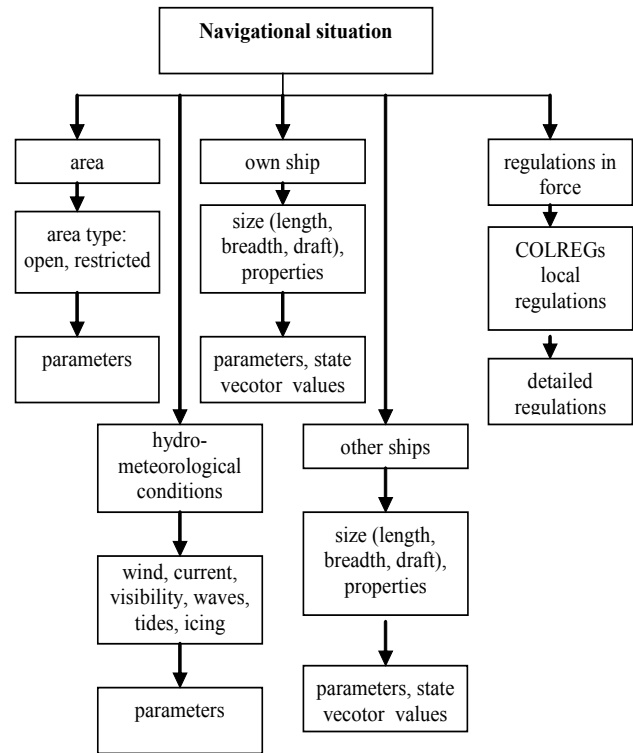

Fig. 1. Model of ship encounter situations

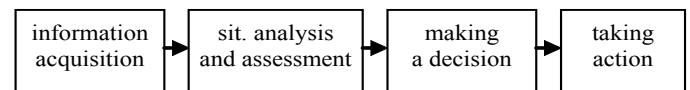Human errors done at each stage of the decision.

Fig. 2. Stages of the decision making process

On this basis detailed fault trees for normal and failure states were drawn.

Making use of the available literature and gathered experimental data, density distributions or probability values for elementary events in the modeled event trees were determined.

Basic operators of probability sum and probability product were used for the determination of ship collision probability based on the models designed.

The algorithms was verified using accident statistical data (collisions of ships) in the examined areas.

4 COLLISION CAUSES

Marine accident statistics show that human errors and failures of shipboard equipment and systems are main reasons of ship collisions.

In this analysis of ship collisions and the construction of a relevant fault tree human errors were classified into two groups:

– errors and mistakes: absent-mindedness, lack of attention;
– offences (violation of regulations or procedures): absence on the bridge, falling asleep, accident, illness, alcohol).

In the case of errors and mistakes, there is a possibility of detecting the error based on the three-minute cycle of ship conduct, while in the case of close quarters (collision) situation, due to the obligation of constant observation (Fig. 3).
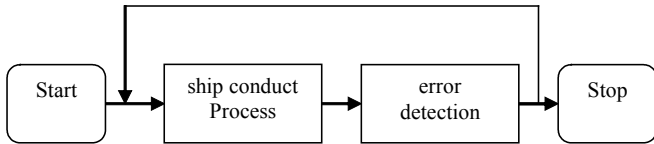

Fig. 3. Ship conduct process

Equipment and system failures were divided into:

– propulsion failure,
– rudder failure,
– blackout.

These events may occur at various stages of the ship conduct process:

– observation (distance between ships 8-12 Nm),
– decision making (distance between ships 4-8 Nm),
– taking action (distance between ships 2-4 Nm) - collision situation.

Taking action by performing a collision preventing manoeuvre follows mostly when the minimum values of the closest point of approach and the time to closest point of approach (CPA_L and $TCPA_L$) are exceeded.. Normally one nautical mile distance is assumed as the closest point of approach and 10 minutes as the time to CPA.

5 FAULT TREE METHOD IN THE ASSESSMENT OF SHIP COLLISION PROBABILITY

The fault tree method consists in writing down relations between events being causes and other events being their effects.

When two ships encounter, possible causes of collision may be both internal to either of the ships, and external to the ships, resulting from traffic conditions in a given area. The causes of undesired events may be divided into two categories:

1 Ship conduct: the ship is capable of navigating safely. Collision risk is only due to navigator's errors;
2 Operational states and the environment: the ship is not capable of navigating safely. The causes are failures to shipboard equipment and systems. A

risk of collision is due to: a) restricted or lacking information necessary in the process of analyzing and assessment of a navigational situation, e.g. due to radar failure in poor visibility; b) restricted manoeuvrability or difficult navigational conditions prevailing in the area.

A collision may be a consequence of such an error as deviation from the collision course. The ships will collide if the error is done on both ships (Fig. 4).
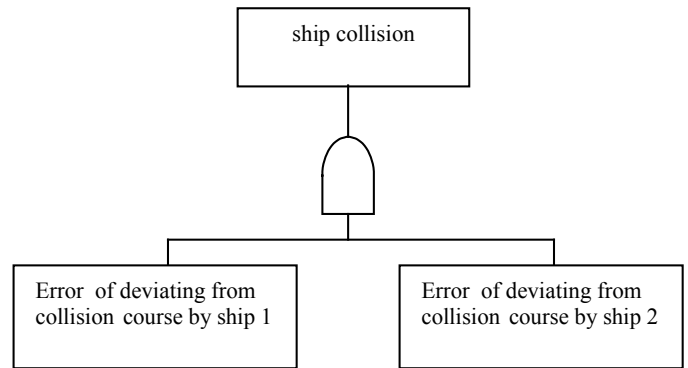

Fig. 4. Fault tree of ship collisions

6 FAULT TREE OF DEVIATING FROM A COLLISION COURSE

Causes of collision course deviation errors are these:

– error of collision situation identification,
– error of preventive manoeuvre performance.

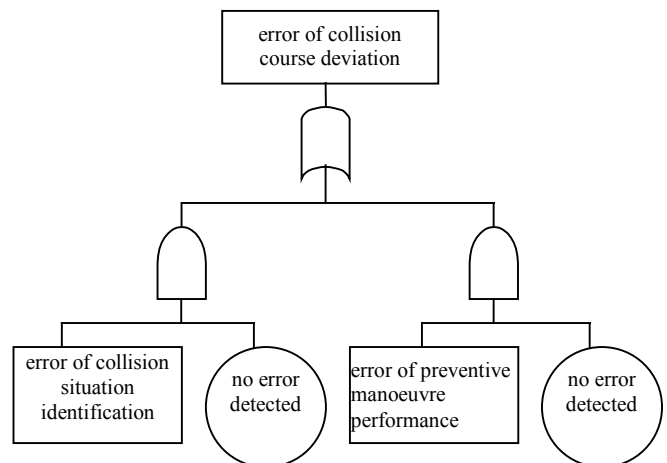The fault tree of the collision course deviation is presented in Fig. 5.

Fig. 5. Fault tree of collision course deviation

7 FAULT TREE OF COLLISION SITUATION IDENTIFICATION ERROR

The errors consisting in wrong identification of a collision situation are as follows:

- error in the determination of the closest point of approach (radar or gyrocompass error),
- human errors,
- radar failure in poor visibility.

It is possible to detect and correct an error in determining the closest point of approach or an error due to absent-mindedness in subsequent cycles of ship conduct. The fault tree of the collision situation identification error is presented in Fig. 6.

8 FAULT TREE OF PREVENTIVE MANOEUVRE PERFORMANCE ERROR

The causes of errors in performing a collision preventing manoeuvre may be these:

- failing to perform a manoeuvre due to human errors,
- failing to perform a manoeuvre due to rudder or propulsion failure or blackout,
- wrong manoeuvring parameters (insufficient course or speed alteration).
- wrong ship command (error in giving a command, error in performing a command).

Due to the fact that in open sea navigation the most frequent collision avoiding manoeuvre is an alteration of the ship's course, the fault tree does not take include speed alteration (Fig. 7).
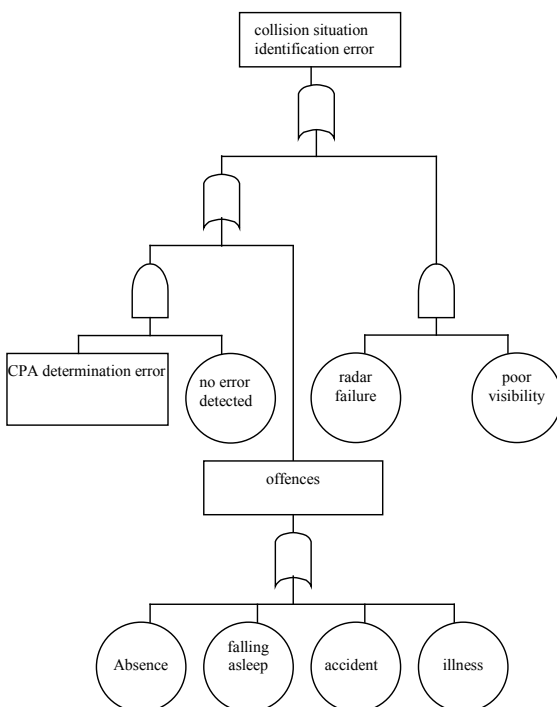

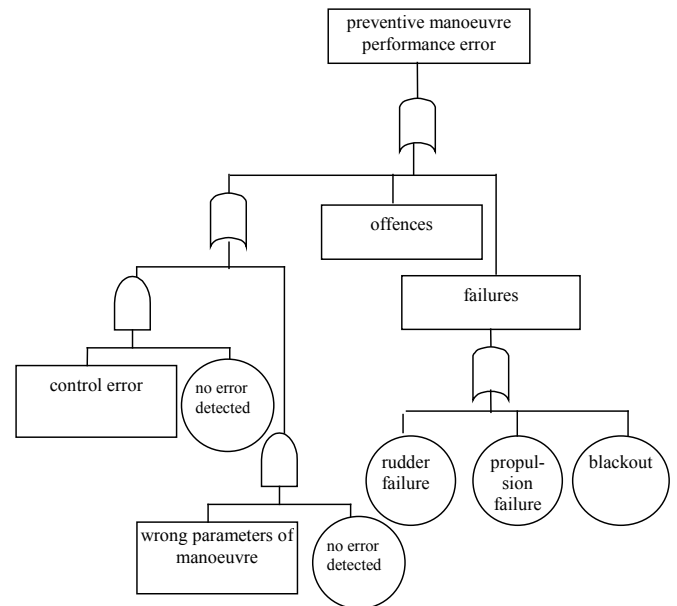Fig. 6. Fault tree of a collision situation identification error

Fig. 7. Fault tree of preventive manoeuvre performance error

The presented fault trees provide a basis for building corresponding event trees, enabling the determination of ship collision probability in open sea navigation.

9 SUMMARY

A method of navigational safety assessment based on probabilistic methods has been presented. This method enables the determination of ship collision probability in a situation where ships encounter in an open sea area. The collision probability has been determined by using methods of fault tree and event tree analyses. On this basis we can estimate the navigational risk and examine ways of counteracting and reducing risks in vessel traffic – risk management in sea transport, which is of major importance for the assurance of safe navigation, thus for the safety of people, cargo, ship and the marine environment.

REFERENCES

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