THE ARCHIVES OF TRANSPORT

VOL. XXIV NO 3 2012

10.2478/v10174-012-0017-1

# Safety Management of Complex Airborne and Seaborne Technical Objects

Mirosław Gerigk*
Jacek Skorupski**

Received June 2012

**Abstract**

The paper presents some information on a concept of the safety management method of the complex airborne and seaborne technical objects. First of all the differences in safety management in both the seaborne transportation and airborne transportation are introduced. Then the safety system which may be applied for the complex technical objects is described. Next the method for safety assessment of the complex technical airborne and seaborne objects based on the risk assessment is presented. Then the chosen elements of the risk model are described. In the final part of paper the proposed method of safety management of the complex technical objects devoted to the seaborne and airborne applications is introduced. Finally the conclusions are given.

## 1. Introduction

Operation of the complex technical objects treated as the systems is connected with the necessity of permanent safety management when an object is in either undamaged or damaged conditions.

There are substantial differences concerning the safety management of the complex technical objects in undamaged and damaged conditions and these concern both the seaborne and airborne transportation. There are some differences regarding the safety management systems in both the domains of transportation.

The differences associated with the approach to safety management in these domains follow from the different sources and they may concern as follows [1-15]:

1) an object as a technical system (including the internal technical subsystems),

* Politechnika Gdańska, Wydział Oceanotechniki i Okrętownictwa
** Politechnika Warszawska, Wydział Transportu

2) features of an object (including an object performance),

3) infrastructure (technical environment) where an object mission is performed (including the air ways, sea ways, external technical subsystems),

4) legislation (including the conventions, regulations, guidelines),

5) procedures of an object management (including the operational procedures),

6) natural environment (airborne transportation - wind, fog, air temperature; waterborne transportation - sea waves, wind, fog, temperature),

7) human factor.

The biggest differences in management of seaborne and waterborne objects concern the legislation and operational procedures. These differences mainly follow from the history of development of these transportation domains. In the case of airborne transportation a permanent development was continued during the last one hundred years. The most effective were the last fifty years. In the case of the waterborne transportation this is more than one hundred years in respect to legislation.

The differences connected with the air and water environment are obvious.

The similarities regarding the approach to safety management of both the transportation domains and objects are as follows [1-15]:

1) airborne and waterborne objects are the complex anthropological systems (man-object-environment),

2) nature of motion in both the cases is similar; both the objects (aircrafts and ships) move in the fluid medium; performance of these objects is estimated in the similar way as well; differences in description of motion mainly follow from the features of the fluid in which the object move; this is closely associated with the nature of inertia, damping and restoring forces acting on the object body,

3) there are some similarities connected with the air ways and water ways; for example it concerns the definitions of traffic separation,

4) some external technical subsystems are similar in both the domains; for example it concerns the communication and navigational subsystems,

5) legislation and object management procedures are of global (conventions, regulations, guidelines) and local character in both the domain of transportation,

6) there are some similarities taking into account the human factor impact; for example it concerns the decisions made by the aircraft or ship captain.

## 2. Safety System of a Complex Technical Object

According to the above mentioned information a generic safety system of the complex technical objects including the aircrafts and ships may be presented as it is shown in Fig. 1.

The structure of interrelations existing between the data elements of the safety system of complex technical object including an aircraft or ship may be presented as it is in Fig. 2.

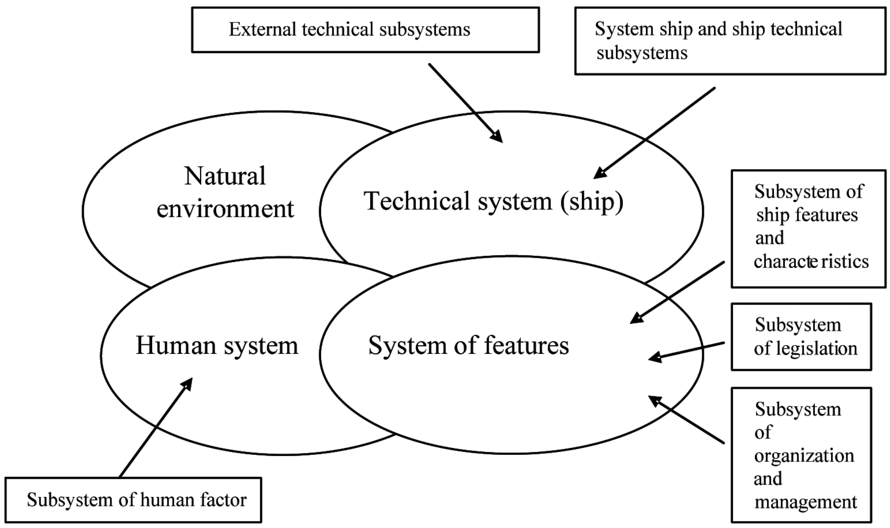


Fig. 1. Generic safety system of the complex technical objects including the aircrafts and ships

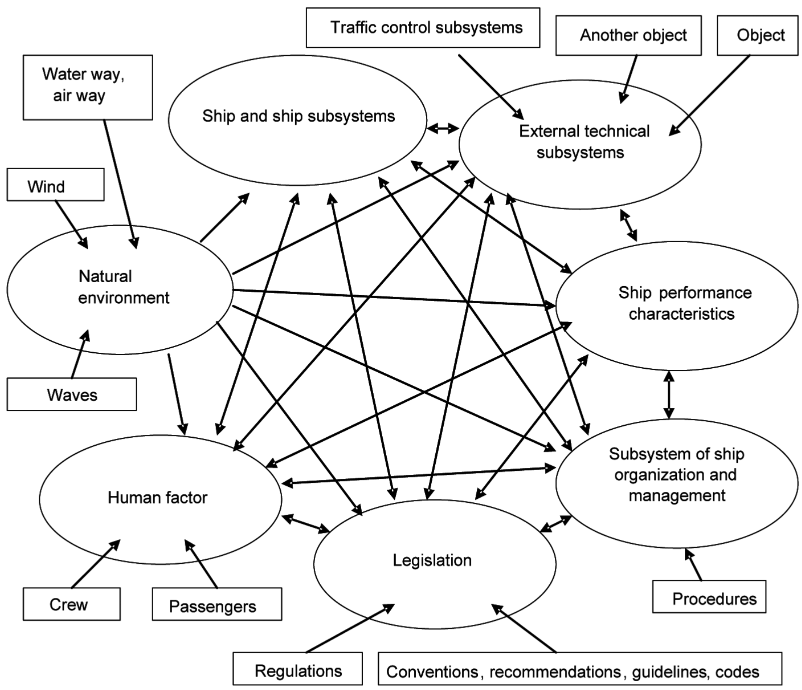


Fig. 2. The structure of interrelations existing between the data elements of the safety system of complex technical object including an aircraft or ship

It is shown in Fig. 2 that there is no possibility to influence the natural environment by the other elements of the safety system which is according to the reality.

The safety systems presented in Fig. 1 and Fig. 2 are the basis of safety assessment of the objects under consideration.

There is a group of factors affecting the safety of an object according to the holistic approach to safety. These factors are as follows:

1) design factor - it exists at the object design stage (including the object parameters, aerodynamic characteristics, hydrodynamic characteristics, object features),

2) operational factor - it exists during the operation of object (including the object operational parameters and characteristics: loading condition, speed, course (heading), ceiling),

3) factor connected with the object organization and management (including the safety culture: management at the airport, management in the air space, management in the port area),

4) human factor.

It follows from Fig. 1 and Fig. 2 that the hazards existing during the operation of the complex technical objects including the aircrafts and ships follow from the interactions between different elements and factors. The most important sources of hazards in the airborne transportation are as follows: human factor, aircraft, organization and management and both the natural and artificial (internal and external from the object point of view) environment [8].

The system structures presented in Fig 1 and Fig. 2 were developed for the ships [3] therefore it may be underlined that the safety systems in the case of the complex technical objects as the aircrafts and ships have a very similar structure. Of course they may be different in respect to details.

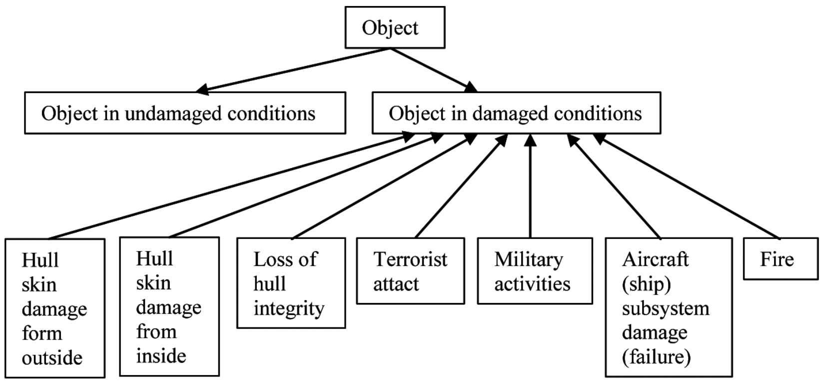


Fig. 3. The system of factors in the form of accident categories which may cause that an object (ship or aircraft) can be in damaged conditions

During the further analysis it has appeared that the similarities concern the system of factors in the form of accident categories. The categories of accident as the hazards which may cause that an object (ship or aircraft) can be in damaged conditions are presented in Fig. 3 [3].

## 3. Method of Safety Assessment of the Complex Airborne and Waterborne Technical Objects Based on the Risk Assessment

The safety assessment of the airborne and waterborne objects in undamaged and damaged conditions within the proposed method is based on both the assessment of object performance and risk assessment. The major characteristic of the method is that for the safety assessment of an object the holistic approach has been applied.

This approach is associated with using as follows:

1) holistic risk model,

2) factors affecting the object safety follow from the different sources as follows: design, operation, management and human factor.

For assessment of the object performance the following methods may be applied:

1) investigations with using the physical models,

2) computer simulation.

The assessment of an object performance in undamaged and damaged conditions enables prediction of all the possible scenarios of accident including the accident consequences. The assessment of an object performance is the base for building the event trees ETA [3, 4].

The risk assessment is associated first of all with the risk estimation according to the event trees ETA prepared before. For the risk estimation the risk model presented in the following chapter may be implemented. The risk assessment itself can be done using the acceptance criteria (RAC – Risk Acceptance Criteria). Within the proposed method the risk matrix or ALARP concept may be applied for the risk assessment procedure [3, 4].

The main objective when using the proposed method is to obtain an adequate risk level. Such the approach is equal to this that within the proposed method the safety of an object is treated as the aim (as the main objective): design objective, operational objective and managerial objective. The major measure of safety within the proposed method is the risk level.

The proposed method can be applied at any stage of object life including a catastrophe at sea. The structure of the proposed method is presented in Fig. 4 [3].

## 4. Chosen Elements of the Risk Model

The risk associated with the different hazards and scenario development was estimated according to the well known general formulae [3]:

$$R_i = P_i \times C_i \tag{1}$$

where:

$P_i$ – probability of occurrence of a given hazard;

$C_i$ – consequences following the occurrence of the data hazard and scenario development, in terms of fatalities, injuries, property losses and damage to the environment.

The risk model (1) may have four different kinds of losses regarding the human fatalities (HF), cargo and ship losses (CS), environment pollution (E) and financial losses ($) and for the ship in damaged conditions can be presented as follows:

$$R = P_z P_{szbo/z} P_{uo} C_w \tag{2}$$

where:

$P_z$ – probability of the data hazard occurrence;

$P_{szbo/z}$ – probability of the data scenario occurrence conditional on the data hazard occurrence;

$P_{uo}$ – probability of losing the object conditional on the data scenario occurrence and conditional on the data hazard occurrence;

$C_w$ – consequences regarding the fatalities, property (cargo, ship), environment and finance ($C = C_{HF/C}, C_{CS/C}, C_{E/C}, C_{\$/C}$) estimated at each stage of the accident.

The $P_{uo}$ probability can be estimated during the accident at sea using the following methods [3]:

1) binary method;
2) method based on definition of the static's characteristics of the object;
3) method based on definition of the object performance during the accident.

In the case of the last method the surge, sway, heave, roll, pitch and yaw functions in time domain have been anticipated as the major characteristics enabling the risk assessment [3].

The risk analysis requires to calculate the conditional probabilities regarding the initial events $ZI_i$, major events (hazards) $ZG_j$, intermediate events $ZP_k$ and final events $ZK_l$ which can be treated as consequences. The basic mathematical formula are as follows [3].

First of all the row matrix of initial events is evaluated:

$$P(ZI) = P(ZI_i) \quad \text{for} \quad i = 1 \ \text{to } n \tag{3}$$

Then the matrix of major events is calculated:

$$MP_{ZG} = P(ZG_j/ZI_i) \quad \text{for} \quad j = 1 \ \text{to } m \tag{4}$$

After that the matrix of intermediate events is calculated:

$$MP_{ZP} = P(ZP_k/ZG_j) \quad \text{for} \quad k = 1 \ \text{to } m1 \tag{5}$$

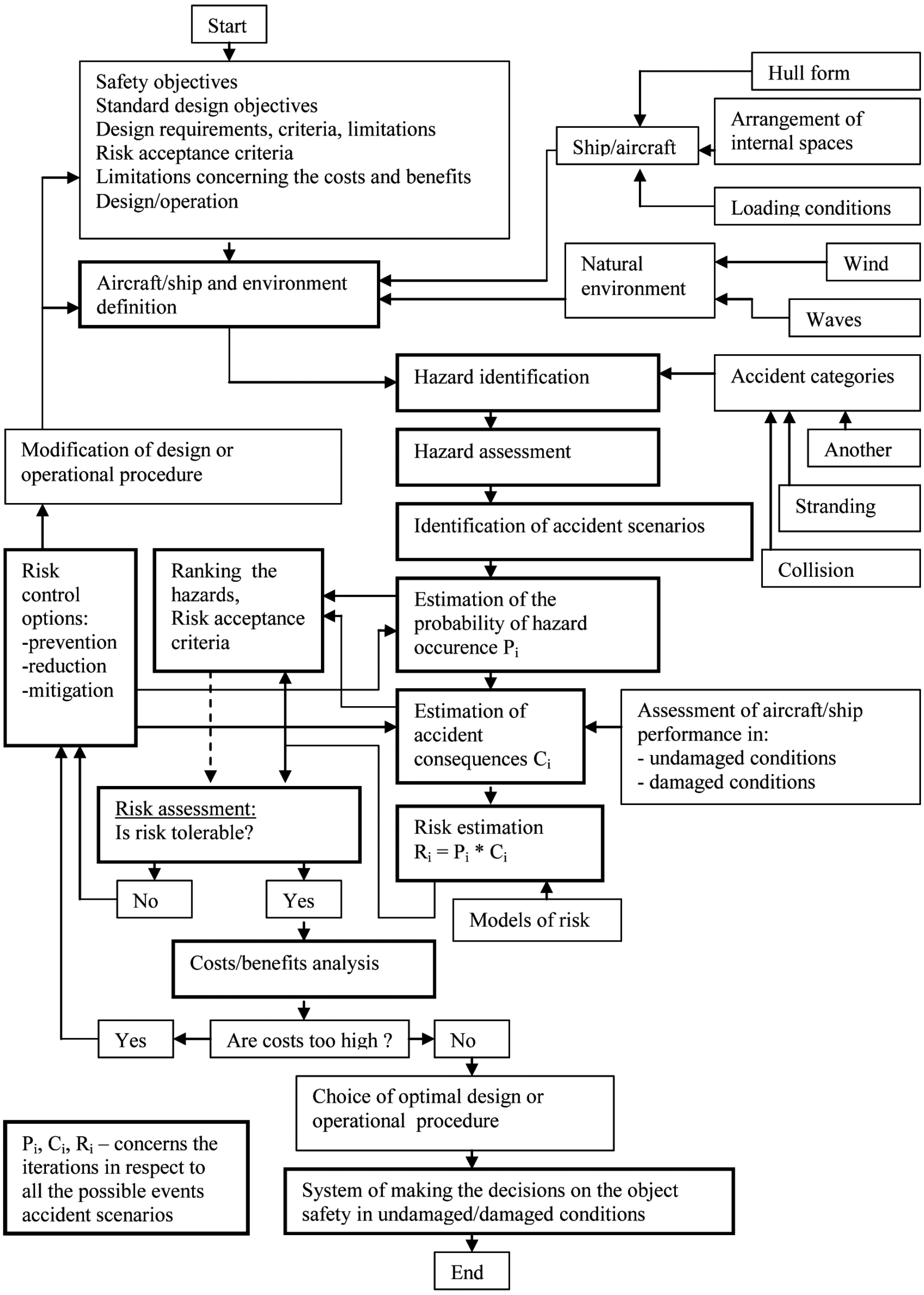


Fig. 4. The structure of the proposed method of safety assessment of complex technical objects which is based on the performance assessment and risk assessment

Then the matrix of final events is calculated:

$$MP_{ZK} = P(ZK_l/ZP_k) \quad \text{for} \quad l = 1 \text{ to } m2 \tag{6}$$

Finally, the row matrix of final events may be estimated as follows:

$$P(ZK) = P(ZI)MP_{ZG}MP_{ZP}MP_{ZK} \tag{7}$$

Because of the above mathematical model used the entire risk model is called as the matrix type risk model. The risk model enables to consider many possible scenarios of an accident using the event trees ETA. In the case when the additional events $ZA_{k1}$ occur the $P_{uo}$ probability can be calculated according to the formula presented by Gerigk [3]. The typical additional events may concern the water on deck, air cushions, cargo leakage, additional heeling moments or passenger behaviour.

## 5. The Proposed Method of Safety Management of the Complex Technical Objects Directed to Airborne and Waterborne Applications

The safety management system consists of the elements and relations between them which in operation and during a catastrophe enable as follows:

1) taking into account the influence on safety of all the safety factors;
2) risk assessment;
3) risk management.

The risk management is possible if the risk assessment is done and it is associated with answering the following questions:

1) what to do to decrease the risk?
2) what are the costs to decrease the risk?
3) what influence of this decrease is on the future solutions concerning the object safety?

The risk management may be defined as a systematic and holistic process which enables the quantitative risk assessment and risk management taking into account the relations existing within the object safety system as presented in Fig. 1 and Fig. 2 [3]. The safety system consists of the elements and interrelations existing between these elements which may an impact on the object safety.

The risk management within the method of object safety management is based on the strategy of risk reduction as follows [3, 16]:

1) reduction of the probability of the data events occurrence which consists of:
   1.1) reduction of the probability of the intermediate events $ZP_k$ occurrence,
   1.2) reduction of the probability of the intermediate events $ZA_{k1}$ occurrence,
2) reduction of consequences which consists of the reduction of the probability of the final events $ZK_l$ occurrence.

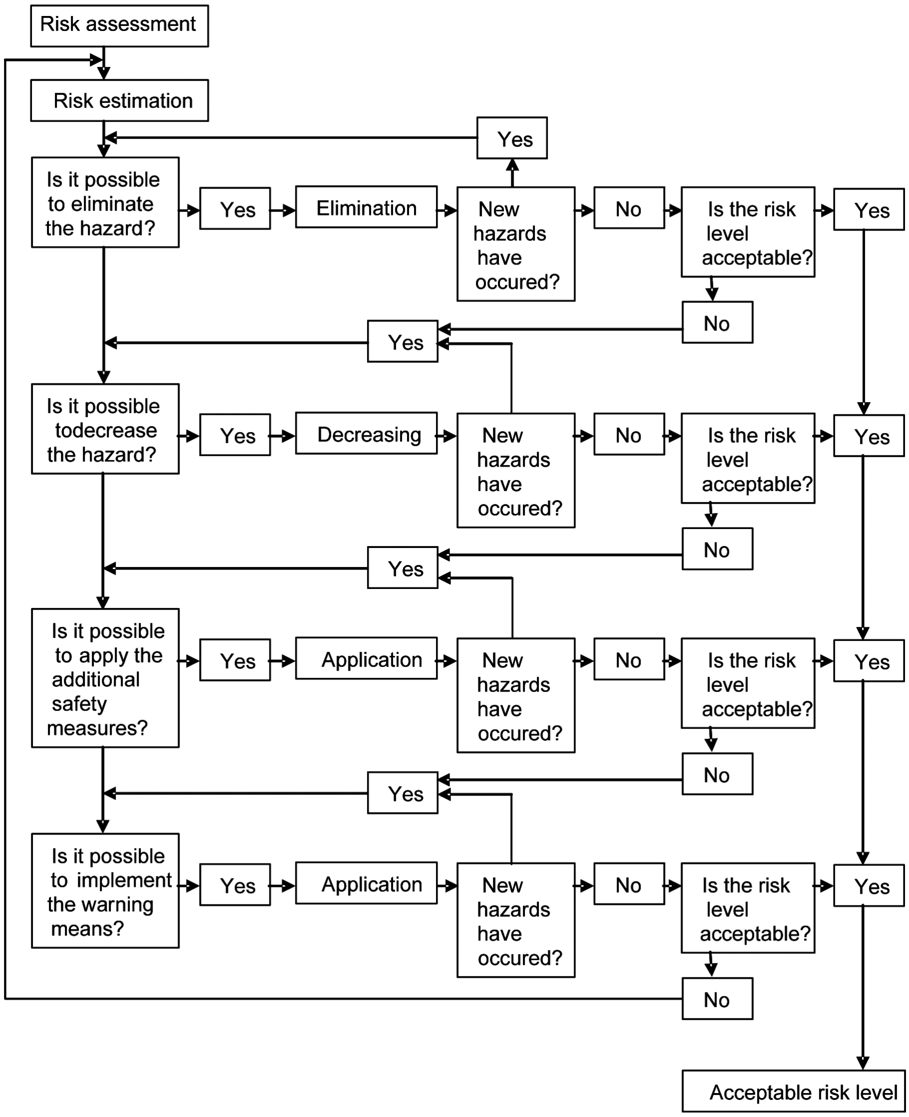


Fig. 5. The structure of the safety management system of the complex technical objects concerning the application in the waterborne and airborne transportation

The structure of the safety management system of the complex technical objects for the waterborne and airborne applications is presented in Fig. 5.

The dynamics of a catastrophe at sea or in the air requires a rapid making decisions concerning the object safety. It should be directed towards the safety of human being, property and natural environment. The fast making decisions requires to apply an object in damaged conditions safety system working in the real time. The structure of such the system have been worked out and it is presented in Fig. 6.

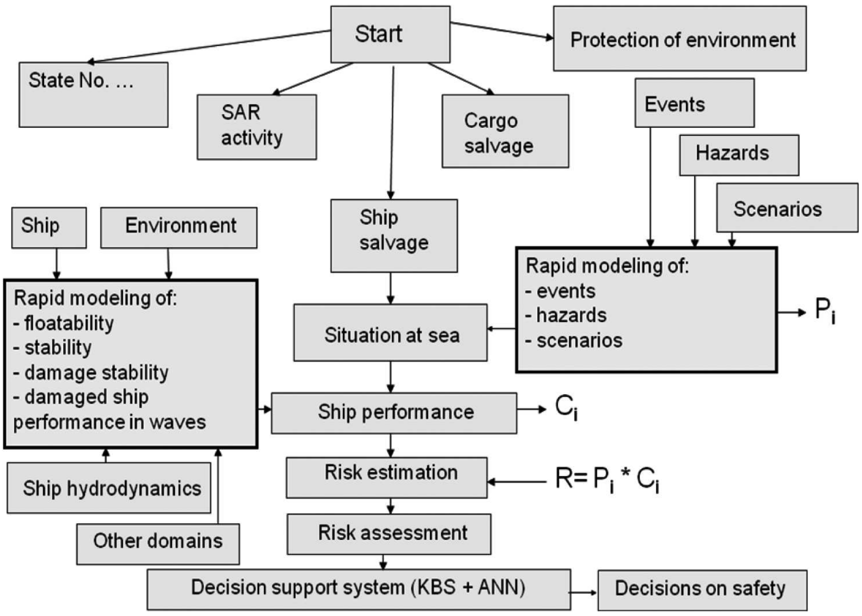


Fig. 6. The structure of the object in damaged conditions safety system which enables the risk and safety assessment during a catastrophe at sea

The functionality of such the system depends very much on the following:

1) a possibility of rapid modelling of a situation at sea (scenarios of accident),

2) a possibility of rapid modelling of the damaged object performance at sea.

The above mentioned follows from the fact that the rapid and effective making decisions during a catastrophe at sea have the direct influence on the safety of human beings, property and environment.

The holistic safety management system of the complex technical object should include many subsystems as follows:

1) subsystem – object (internal and external control and monitoring subsystems including the GPS, GDPS and VTS subsystems);

2) subsystem – environment (wind, waves, wind current, wave current);

3) subsystem – legislation (conventions, recommendations, guidelines, regulations);

4) subsystem – object management (operational procedures);

5) subsystem – safety management system SMS;

6) subsystem – human factor;

7) subsystem – integrated safety management ISM;

8) subsystem – emergency system;

9) subsystem – warning system;

10) subsystem – evacuation;

11) subsystem – rescue.

# 6. Conclusions

In the paper the basic information on the safety management of the complex airborne and waterborne technical objects is presented. The safety system of a complex technical object is introduced. The method of safety assessment of the complex airborne and waterborne technical objects based on the risk assessment is described. Some elements of the risk model is presented as well. The proposed method for safety management of the complex technical objects directed to the waterborne and airborne transport applications is described in the paper.

The objectives of further investigations will be connected with modelling and estimating the conditional probabilities of the hazards, intermediate events, additional events and consequences occurrence. The next step of research activities will be associated with developing the event trees ETA for the practical implementations.

The authors are aware that the definitions and terminology used in the paper mainly belong to the theory of systems and risk analysis domains. At this stage of research it is difficult to combine the knowledge of safety and risk assessment following from the airborne and waterborne domains. In the future there is a necessity to apply further the ready definitions existing within the theory of systems and risk analysis or to try to work out the new definitions and terminology. The second approach could be very useful as the safety of airborne and waterborne systems and objects very often relay on the same solutions following from the different disciplines of knowledge [17, 18].

The research investigations are conducted according to the collaboration between the Gdansk University of Technology, Warsaw University of Technology and Naval Academy in Gdynia.

# Acknowledgements

The authors would like to express their sincere gratitude to the Ministry of Science and Higher Education, for the support to carry out the investigation on novel solutions for the assessment of safety of aircrafts and ships, and Faculty of Ocean Engineering and Ship Technology Gdansk University of Technology and Faculty of Transport Warsaw University of Technology, for the scientific and research support.

## References

1. Downarowicz O.: System of operation (System eksploatacji). Management of technique resources (Zarządzanie zasobami techniki), Monography: Monograficzna seria wydawnicza Biblioteka Problemów Eksploatacji, Gdańsk-Radom 2005.
2. Dudziak J.: Theory of ships (Teoria okrętu), Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej, Gdańsk 2008.
3. Gerigk M.: A complex method for safety assessment of ships in damaged conditions using the risk analysis (Kompleksowa metoda oceny bezpieczeństwa statku w stanie uszkodzonym z uwzględ-

nieniem analizy ryzyka), Monography: Monografie 101, Wydawnictwo Politechniki Gdańskiej, Gdańsk 2010.
4. Gerigk M.: Assessment of safety of ships after the collision and during the ship salvage using the matrix type risk model and uncertainties, Proceedings of the 14th International Congress of the International Maritime Association of the Mediterranean (IMAM), Volume 2, Genova, Italy, 13-16 September 2011.
5. IMO (International Maritime Organization). Resolution MSC.194(80) Annex 2, Adoption of Amendments to the International Convention for the Safety of Life at Sea, 1974, As Amended, adopted on 20.05.2005.
6. IMO (International Maritime Organization). Resolution MSC.216(82) Annex 2, Adoption of Amendments to the International Convention for the Safety of Life at Sea, 1974, As Amended, adopted on 08.12.2006.
7. Jasionowski A., Vassalos D.: Conceptualising Risk, Proceedings of the 9th International Conference on Stability of Ships and Ocean Vehicles STAB 2006, Rio de Janeiro, 25-29 September 2006.
8. Klich E., Szczygieł J.: Safety of air flights in airborne transportation (Bezpieczeństwo lotów w transporcie lotniczym), Monography: Monograficzna seria wydawnicza Biblioteka Problemów Eksploatacji, Radom 2010.
9. Lewitowicz J.: Fundamentals of operation of aircrafts (Podstawy eksploatacji statków lotniczych). Systems of operation of aircrafts (Systemy eksploatacji statków powietrznych), Wydawnictwo Instytutu Technicznego Wojsk Lotniczych, Warszawa 2006.
10. Łucjanek W., Sibilski K.: Introduction to dynamics of helicopters (Wstęp do dynamiki lotu śmigłowca), Wydawnictwo Instytutu Technicznego Wojsk Lotniczych, Warszawa 2007.
11. Sibilski K.: Modeling and simulation of dynamics of the aircraft move (Modelowanie i symulacja dynamiki ruchu obiektów latających), Oficyna Wydawnicza MH, Biblioteczka Nauka-Innowacje-Technika NIT, Warszawa 2004.
12. Smalko Z.: Terminology considerations on the transport safety engineering (Studium terminologiczne inżynierii bezpieczeństwa transportu), Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2010.
13. Skjong R., Vanem E., Rusas S., Olufsen O.: Holistic and Risk Based Approach to Collision Damage Stability of Passenger Ships. Proceedings of the 9th International Conference on Stability of Ships and Ocean Vehicles STAB 2006, Rio de Janeiro, 25-29 September 2006.
14. Wawrzyński W.: Safety of steering systems in transport (Bezpieczeństwo systemów sterowania w transporcie), Monography: Monograficzna seria wydawnicza Biblioteka Problemów Eksploatacji, Warszawa-Radom 2004.
15. Żurek J.: Modeling of the follow-up safety systems (Modelowanie nadążnych systemów bezpieczeństwa), Monography: Monograficzna seria wydawnicza Biblioteka Problemów Eksploatacji, Radom 2010.
16. Borysiewicz M., Furtek A., Potempski S.: Handbook on the methods of risk assessment for the dangerous processing installations (Poradnik metod ocen ryzyka związanego z niebezpiecznymi instalacjami procesowymi), Instytut Energii Atomowej, Otwock–Świerk 2000.
17. Gutenbaum J.: Mathematical modeling of systems (Modelowanie matematyczne systemów (in Polish)). Polish Academy of Sciences (Polska Akademia Nauk). Akademicka Oficyna Wydawnicza EXIT, Warszawa 2003.
18. Stephans R.A.: System Safety for the 21st Century. The Updated and Revised Edition of System Safety 2000. Wiley-Interscience, A John Wiley & Sons, Inc., Publication, Hoboken, New Jersey, 2004.