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A DYNAMIC RISK ASSESSMENT FOR DECISION SUPPORT SYSTEMS IN THE MARITIME DOMAIN

Summary: The oversea shipping is nowadays one of the key elements of the global trade. Currently about 90% of cargo is carried by sea. With the growing importance of the world seaborne trade, the need to assess the risk posed by ships appears.

The paper presents an approach to analyze the maritime risk, by estimating in real-time the risk level of an individual ship, and thus assess the security of maritime transportation system in the short-term horizon. The approach is based on a dynamic evaluation of risk, using various risk factors and variables.

The aim of the approach is to facilitate the automatic comparison of ships from the point of view of risk they pose. It can be used in decision support systems to classify ships, which require a special attention. The paper presents several business scenarios, where the approach to risk analysis can be applied.

Keywords: decision support systems, risk assessment, maritime risk, maritime shipping.

Introduction

The importance of the world seaborne trade continues to grow throughout the last century [UNCTAD, 2015]. Since 1945 it has doubled every decade [del Pozo et al., 2010]. Nowadays, more than 90 per cent of the global trade is carried by sea [IMO, 2012]. In 2013 about 9,5 billion tons of goods were loaded and travelled between 8000 ports worldwide by more than 103 thousand of commercial ships [IMO, 2012; UNCTAD, 2015]. Increasing globalization, industrialization and liberalization of national economies have driven a free trade and a growing demand for consumer products. Development of technology has also made shipping an increasingly efficient and swift method of transport. Taking into

account all these facts, ensuring the security of the maritime transport and the safety of vessels at sea play nowadays the important role.

The maritime security is the status of the sea conditions under which a threat to health, life, property and marine environment does not exceed the acceptable risk level [Urbański, Morgaś and Specht, 2008]. The security of the maritime transport occurs, when there are three prerequisites met: 1) freedom from danger; 2) freedom from unacceptable risk or personal harm; 3) not losing money [Abramowicz-Gerigk, Burciu and Kamiński, 2013].

The maritime security can be also considered from the point of view of the supply security. It is defined as the level of guarantee that the cargo shipped by a vessel will be successfully delivered to a customer (recipient of the cargo). The measure of the supply security is a risk (a probability of occurrence) of an undesired event (threat), negatively influencing the delivery. This event can be related to human life, ship or environment. As a result, the higher risk posed by a ship, the lower security of supply. Thus the assessment of the maritime risk is required in order to measure the level of the maritime security.

The aim of this paper is to propose a method for the assessment of the maritime risk, by estimating in real-time the risk index of an individual ship, and thus to evaluate the security of the maritime transportation system in the short-term horizon. The approach is about facilitating an automatic comparison of ships from the point of view of risk they pose, in order to use this information in decision making process.

In the research the following methodology was applied to propose the method. In the first step, the authors analyzed the current challenges and needs of the maritime domain with regard to the risk assessment and the maritime threats detection. For this end, a literature review was conducted, which encompassed the recent papers, reports and documentation on existing maritime surveillance systems and risk assessment methods. Moreover, interviews with subject-matter experts were conducted. Based on them the research problem and the scope of the method were defined. It allowed also to identify the variables for the model. The consultations with the expert enabled also to identify the core maritime stakeholders, which may be interested to apply the proposed approach. In the future work, evaluation of the proposed risk assessment method is planned.

The results of these steps are summarized in the remainder of the paper, which is organized as follows: in the next section, related work on a risk assessment and decision support systems in the maritime domain is described. In section 2, a concept of the method for the real-time and individual assessment of risk posed by a ship is presented, followed by various business scenarios, where this approach can be applied. The article concludes with a summary of advantages of the proposed method and future works.

1. Related Work

1.1. Risk Assessment in Maritime Domain

The concept of the maritime risk is defined variously in the literature. Goerlandt and Montewska [2015] present an overview of risk definitions and various approaches to risk analysis in the maritime domain. In the classical approach [ABS, 2000; Szymanek, 2008], risk assessment consists of four basic steps: 1) definition of scenarios of undesirable events (threats identification); 2) calculation of probability for each scenario; 3) calculation of consequences; 4) risk evaluation (determining whether the level of risk is acceptable). In this paper, we limit our discussion to the risk of an undesirable event, which may threaten the safety of individuals, an environment or physical assets. As a result, we define the maritime risk as the probability of occurrence of an undesirable event, or the chance of a loss. This undesirable event may be caused by a ship, due to its features and/or behavior.

In the maritime context, there is a rational and systematic risk-based approach for safety assessment – Formal Safety Assessment (FSA) [Trucco et al., 2008; Berle, Asbjørnslett and Rice, 2011]. FSA was developed by International Maritime Organization, being the basic international institution responsible for developing and maintaining a comprehensive regulatory framework for shipping and thus providing maritime security and safety [Urbański, Morgaś and Specht, 2008]. FSA can be applied to specific maritime safety issues in order to identify cost effective risk reduction options. The FSA process consists of five steps [Ellis et al., 2008; Berle, Asbjørnslett and Rice, 2011]:

1) *Hazard identification* – identification of all hazards related to the activity / ship;
2) *Risk assessment* – building a risk model and determining probabilities and consequences for all branches of the risk model;
3) *Identification of risk control options*, which can mitigate the most important risks;
4) *Costs/benefits assessment* for each option of risk mitigation and preparing a ranking of risk control options;
5) *Recommendations for decision making* – decide and plan the activity, if it is viable.

There are many different analysis techniques and models that have been developed to aid in conducting risk assessments and which are adjusted to the different FSA steps. Since this article focuses only on the risk assessment, mainly the methods used at this step are analyzed.

With regard to identification of threats and risk variables, the commonly used methods are: literature review, brainstorming, HAZOP, FMEA, HAZID [ABS, 2000; Ellis et al., 2008]. Methods for risk modelling can be divided into

qualitative and quantitative. Here popular are statistical analysis (based on historical records) [Soares and Teixeira, 2001; Gerigk, 2012], Fault Tree Analysis, Event Tree Analysis [Berle, Asbjørnslett and Rice, 2011], Bayesian Networks [Trucco et al., 2008; Berle, Asbjørnslett and Rice, 2011], correlation analysis, Fuzzy Logic [Balmat et al., 2009; Elsayed, 2009] or combination of several methods [Eleye-Datubo, Wall and Wang, 2008]. With regard to the risk evaluation, common methods are: risk matrixes, risk profiles, F-N curves or relative ranking/risk indexes [ABS, 2000]. A key issue here is to choose the right method (or combination of methods), which best matches the analyzed situation.

The relative ranking/risk indexing uses attributes of a ship, a port or a waterway to calculate index, which can be further used to make a relative comparison of various alternatives. This method may be used to establish priorities for boarding and inspecting foreign flagged ships [ABS, 2000]. As this paper aims at identification of risky ships, which pose a potential threat, adoption of the risk index approach seems to be the right solution.

Some of the risk assessment methods include also differentiation of critical factors, which more heavily influence the overall risk factor. For this end, either weights are assigned [Liu et al., 2005; Balmat et al., 2009], or only these risk variables are taken into account in estimation of the risk, for which the probabilities are above a defined threshold [Trucco et al., 2008]. Taking into account the fact that risk analysis can be conducted in different contexts, similar solution is included in the proposed method.

1.2. Decision support Systems

A Decision Support System (DSS) is a computer-based information system that supports business or organizational decision-making activities. DSS can be either fully computerized, human or a combination of both. In the maritime domain, mainly human DSS are developed. It means that the information and knowledge, discovered by applying various analysis methods (including results of risk assessment or anomaly detection), are intended as a basis for human decision-making [Riveiro, 2011]. Moreover, in the maritime domain, mainly the ship routing and scheduling DSS, or the navigational DSS are developed (see for example [Fagerholt, 2004; Fagerholt and Lindstad, 2007]. The latter is a component of the maritime intelligent transport system, which supports the process of ship conducting. According to Pietrzykowski [2011], further developments of these systems will be going towards decision support systems – intelligent navigational advisory systems, which apart from information functions will provide a hazard identification in ship movement, a warning against hazards and a generation of recommendations. Such systems would offer a support for a user in the whole risk analysis process.

2. Proposed Approach to Assessment of the Maritime Risk

2.1. Method Overview

In this section, a new approach to the maritime risk assessment for safety at sea is presented. It is based on a real-time and individual risk index, determined based on four types of factors. In this approach, the risk index is a one-dimensional measure, which defines the level of threat from a given ship in a given moment. This measure can be used by a user in order to evaluate ships according to the threat they pose to human life, maritime infrastructure or environment.

The individual risk index means that the risk is assessed for each ship separately, based on its individual characteristics. The real-time index means that the risk level may change over time, since it depends on attributes connected with the actual ship's status, including the actual voyage and conditions during this voyage.

The aim of the method is to identify risky ships in real time and thus generate a recommendation for maritime operators or port authorities, which ships pose a potential threat and need a special attention. Identification of such ships is an essential issue for human, environment and maritime transport infrastructure protection [Balmat et al., 2009]. The method is to provide a flexible decision support tool, which can be used in the existing systems, such as Vessel Traffic Service (VTS) information systems and intelligent navigational advisory systems, or in the DSS dedicated for the maritime domain. The proposed method is dedicated for cargo ships of various types (general cargo, tankers, containers, dry bulk carriers, multi-purpose vessels) and it focuses on one of the FSA methodology step, namely *the risk assessment*.

2.2. Risk Factors

The threat, posed by a given ship, depends on many risk variables or factors, which together indicate the overall level of threat the ship poses. In the proposed approach, the risk variables are grouped into four classifiers (risk factors) (Fig. 1):
– Static risk factor – includes static characteristics of a ship;
– Voyage-related risk factor – includes characteristics of an actual ship's voyage from port to port;
– Dynamic risk factor – includes dynamic variables, which can change during a single ship's voyage, and
– History-related ship factor – includes historical information about a ship.
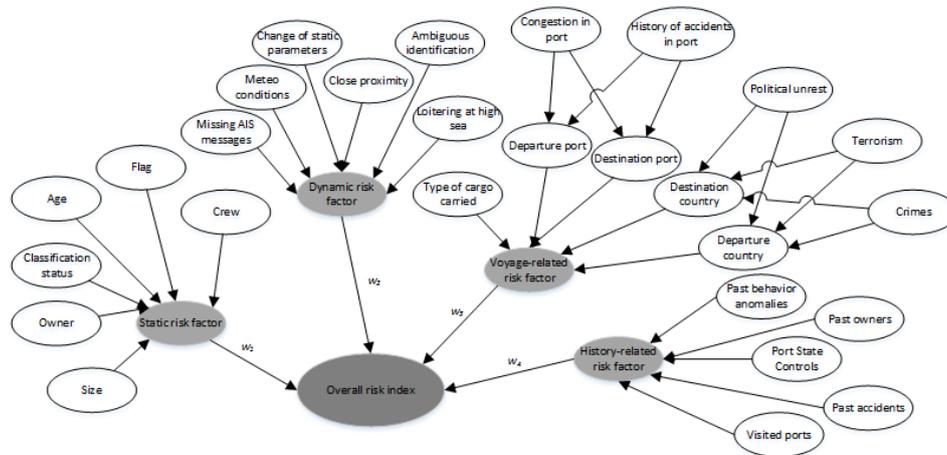
Fig. 1. Risk variables and factors

The static risk factor depends on actual values of static ship's features. It can include such variables as: size, age, owner (known/unknown, owner on a list of poor performing companies), flag, classification status, crew size and experience etc. Some of these variables can change from time to time (e.g. owner, classification status), while the other are rather the same for the ship's lifetime (e.g. size, type).

The voyage risk factor is associated with a specified ship's voyage from port to port. It takes into account characteristics of departure and destination port (congestion, history of accidents), state of departure and destination (political unrest, corruption, civil disorders, terrorism, crimes etc.) and type of cargo carried (dangerous, harmful substances). In general, it includes variables, whose values change with each new voyage.

The dynamic risk factor includes data, which can change during a particular voyage. Generally, it takes into account different anomalies in ship's behavior at sea, such as: missing elements in position reports sent by a ship (AIS messages), sudden changes in ship's name, type, identification number, ambiguous or invalid identification number, outlier trajectory of a ship's route, loitering at the high sea, unreasonable close proximity to other ships. It may also include meteorological conditions at the sea.

The last risk factor is connected with historical information about a ship. Here the following variables can be included: past anomalies in ship's behavior, history of accidents, port state controls and detentions in ports, past owners and flags, history of visited ports.

2.3. Risk Assessment

Using the above-mentioned four risk factors, the overall risk index for a ship can be estimated. The overall index is about determining the potential threat posed by a given ship. The method assumes that the overall risk index is calculated based on weighted risk factors (static, dynamic, voyage- and history-related), where the weight of a particular factor can be adjusted in order to reflect its relative importance in a given context:

$$Overall\ Risk\ Index = \sum_{i=1}^{N} w_i f_i$$

$$w_i \geq 1$$

$$\sum_{i=1}^{N} w_i = 1$$

where N is the number of risk factors, f_i is the value of the given risk factor and w_i is the assigned weight.

Incorporation of the weights in the model results from the fact, that the risk assessment can be conducted in different contexts and its result can be used by different stakeholders (examples are described further in section 3). For each such context, different variables or factors can be critical. Therefore the proposed risk factors are additionally weighted, taking into account their importance in a given business scenario. Besides, one of the issues in the design of decision making systems is the large number of input variables, which need to be considered. As a result, it is difficult to design a system based entirely on expert knowledge. For this reason, here a hierarchical architecture consisting of four risk factors is proposed. In this approach each factor includes variables, which can be estimated using either analytical methods either an expert opinion.

Having estimation of the individual risk index, a ranking of ships, in terms of risk they pose, can be created. The ships with risk level above a defined threshold should be treated as particularly dangerous and more attention should be paid to them. Similarly like with the risk factors, also here the value of the risk threshold may be adjusted to a particular business scenario.

Each variable in the model (e.g. age, type) can have a positive or a negative effect on the likelihood that a ship pose a potential threat. They can be link to a particular risk factor through quantification. This quantification can be addressed by applying various methods, such as paired comparisons (correlation of different variables), direct or indirect numerical estimation or ranking and rating [Eleye-

Datubo, Wall and Wang, 2008]. In case of qualitative data, a fuzzy logic can be applied – it is used, when information associated with a variable is vague, imprecise or linguistic (e.g. expert opinion), and it is unable to establish a strong correlation between premise and conclusion (e.g. experience of a crew or congestion in a port can be specified using a linguistic terms as "low, medium, high", instead of providing a numerical values).

In the proposed method both approaches to variables is planned. If there would be sufficient amount of quantitative data (e.g. historical data about accidents, actual data about ships), the data may be used to model a probability distribution and perform further quantitative reasoning, for example based on Bayes theorem. Another approach may be applied in case of qualitative data (fuzzy variables). In that case, a rule-based inference based on IF-THEN rules [Elsayed, 2009], and conversion of fuzzy variables into probability distribution need to take place. Eleye-Datubo, Wall and Wang [2008] proposed such a transformation method, which can be used here. Another solution is to use methods, which allow combining both qualitative and quantitative variables, such as logistic regression [Larose, 2012].

Apart from quantification of probability based on a single risk variable, the key task is to determine the parametric relationship between one risk variable and another in order to estimate the risk factor. It can be done by performing statistical analysis (e.g. multiple correlation, logistic regression or Bayesian inference), simulation or expert opinion [Eleye-Datubo, Wall and Wang, 2008]. In case of relationships between fuzzy variables, specific IF-THEN rules can be created.

Another approach to determine a value of risk factor is Belief Bayesian Network (BBN). BBN allows to exploit different information, deterministic or probabilistic, emerging from the real world, under the condition of complex relations between a large number of variables [Eleye-Datubo, Wall and Wang, 2008]. In the proposed method, it can be used as a modelling tool to quantify the structure of risk variables in order to obtain an estimation of level of threat from a ship (risk factor), given a specific configuration of variables. Moreover, the Bayesian approach is an aid for a decision-making process and a framework for dynamic systems [Trucco et al., 2008].

In the future work, various approaches to estimate the four risk factors will be considered and tested, including the above mentioned multiple correlation, logistic regression, Bayesian inference and BBN. Selection of the method will depend on the scope of data available for the analysis. Data sources, which are considered to test the proposed method are described in the following section. Another method selection criterion is the amount of available data. In case of

data of high volume or variety (like AIS data), a Big Data approach may be utilized, to discover new correlations between risk variables and ensure the real-time processing and calculation of risk index. Such approaches are already successfully used in other domains [Ansari, Li and Zhang, 2014].

2.4. Data Sources

In order to assess the maritime risk, various data sources may be used. In this section some examples are presented, which are considered to perform the risk assessment of an individual ship using the proposed method.

There are several open databases, which supply information related to ships and their features. Some of them collect data regarding ship's accidents (e.g. International Maritime Organization[1]), inspections and detentions of ships (Memorandum of Understanding of Paris[2], Tokyo[3] or Indian Ocean[4]), or ship's characteristics (e.g. IACS[5], MarineTraffic[6]).

Another source is Automatic Identification System (AIS). AIS is an automatic tracking system used for identifying and locating vessels in real-time. It has been created as a tool for the avoidance of collision at sea and is based on automatic exchange of data about a ship's position and its movement with other nearby ships, base stations, or satellites. It includes navigational data (position, course, speed, navigational status), static data (ship's identity, type, name, call sign) and voyage data (destination port, estimated time of arrival). Nowadays, AIS is used as one of the main data source in the maritime surveillance [Carson-Jackson, 2012]. Based on AIS data various analysis can be conducted. First of all, detection of various anomalies in ship's behavior, based on information about ship's trajectories, position, speed, course etc. Such analysis can indicate, whether a ship poses a potential threat or not[7]. Therefore, AIS may be used as the main data source to perform risk assessment of ship's in real-time.

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[1] https://gisis.imo.org.
[2] https://www.parismou.org/.
[3] http://www.tokyo-mou.org/.
[4] http://www.iomou.org/.
[5] http://www.iacs.org.uk/.
[6] http://www.marinetraffic.com/.
[7] Methods for detection of maritime anomalies based on AIS are subject of other research being conducted right now in the Department of Information Systems, Poznań University of Economics. The results of this research will be used as another source of data for the method.

3. Business Scenarios

The proposed method for estimation of the ship's risk index can be helpful or useful for different stakeholders, working in the maritime domain. The method may be used in different contexts and implemented in decision support systems dedicated for different groups of users. As a result, different business scenarios for utilization of the proposed method can be defined. Examples of the potential maritime users are:

– Port authorities (maritime office, customs services, SAR and other) – interested in a quick identification of suspicious ships, which pose a threat to the port security (critical infrastructure, continuity of supply etc.) and should be inspected;

– State authorities – want to know whether there exists any threat for supply of the key resources to the country (e.g. supply of oil and gas);

– Senders of goods carried by a ship – want to know whether the goods will be delivered without disruptions and whether the ship is the safe mean of transport;

– Recipients of goods carried by a ship – similarly to senders, want to know, what is the probability that the goods will be delivered without disruptions;

– Logistics companies, which uses services of maritime shipping companies – based on the level of risk posed by a ship, they can decide, which ships or carriers to choose for cargo shipping;

– Ship owners / operators – interested in performing a comparison of risk posed by their fleet and fleet of competitors and based on that determine attributes of shipping service (e.g. freight), and

– Ship's captains – want to know whether there is any risky ship nearby.

It needs to be stressed that for each above-mentioned user, different risk attributes or risk factors can have different value. For example, in estimating the risk index of a ship, for logistic companies or senders of goods static factors and historical anomalies may be more important in determining the risk, while for captains or port authorities dynamic or voyage-related attributes may be more relevant. Therefore weights for variables and risk factors are incorporated to the method.

Summary

Detection of the high risk ships is the important topic from the point of view of improving safety at sea. It affects various maritime stakeholders, which require information about risky ships to effectively realize maritime surveillance and be able to make decisions. Therefore in this article, we propose the risk modeling approach for cargo ships, which provide the individual risk index based on 4 risk factors.

The proposed method have some advantages in comparison to the existing methods for the assessment of ship's risk. Firstly, it assumes analysis of the overall risk posed by a ship. The existing methods focus either on estimating the risk of a specified hazard (e.g. collision, grounding, fire), undesired events connected with the ship's technical attributes (e.g. problem with an engine, machinery) or a human error [Cross and Ballesio, 2003; Eleye-Datubo, Wall and Wang, 2008; Ellis et al., 2008]. Secondly, it takes into account four different risk factors, while in most cases only one type of factor is included (e.g. human error, technical characteristics or environmental conditions) [Lam, 2012]. Moreover, it includes the variables, which have not been so widely used in the risk assessment, such as current and historical anomalies in ship's behavior, detected based on AIS data and history of a ship. Instead, other methods focus on technical characteristics of ports, crew experience, efficiency of support staff, effectiveness of the emergency system on board etc. Finally, the method provides individual and real-time risk index. Thus, it can be used to determine the short-term security of supplies, while most of the published analysis and strategies focus on the long- or mid-term security (especially, when it comes to supply of the key energy resources) [Kowalski and Kozera, 2009]. From the business perspective, the proposed approach can be used in various business scenarios and thus be implemented in decision support systems dedicated for various maritime stakeholders. As a result, it addresses the need for development of DSS for the maritime domain.

This article aims only at presenting the concept of the method. Future research will be devoted at testing the approach on a set of case studies, using the real data about ships, retrieved from data sources mentioned in Section 2.4. Then experiments, aiming at defining weights and risk threshold for various business scenarios distinguishing risky ships, will be performed.

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DYNAMICZNA OCENA RYZYKA DLA SYSTEMÓW WSPOMAGANIA DECYZJI W SEKTORZE MORSKIM

Streszczenie: Transport morski jest jednym z kluczowych elementów globalnego handlu. Obecnie ok. 90% towarów jest przewożonych drogą morską. Wraz ze wzrostem znaczenia światowego handlu morskiego pojawia się potrzeba oceny ryzyka stwarzanego przez statki.

W artykule zaprezentowano propozycję podejścia do analizy ryzyka morskiego, opierając się na szacowaniu w czasie rzeczywistym poziomu ryzyka pojedynczego statku, a tym samym oceny bezpieczeństwa morskiego systemu transportowego w krótkim horyzoncie czasowym. Podejście skupia się na dynamicznej ocenie ryzyka, bazując na szeregu czynników i zmiennych odnoszących się do ryzyka.

Zaproponowana metoda ma na celu ułatwić porównanie statków z punktu widzenia ryzyka, jakie stwarzają. Może ona być zastosowana w systemach wspomagania decyzji jako klasyfikator statków wymagających szczególnej uwagi. W artykule przedstawiono kilka scenariuszy biznesowych, w których proponowane podejście do analizy ryzyka statku może być stosowane.

Słowa kluczowe: systemy wspomagania decyzji, ocena ryzyka, żegluga morska, ryzyko morskie.