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Review of collision and grounding risk analysis methods which can utilize the historical AIS data and traffic patterns in seawaters

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SE 3.2 Methods for assessing safety and security performance

- SE3.2.1 **Review of collision and grounding risk analysis methods which can utilize the historical AIS data and traffic patterns in seaways**
- SE3.2.2 Evaluation of methods to estimate the consequence costs of an oil spill
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Key Findings / Conclusions	Five of the methods can be applied to all sea areas. One method is designed to be applied in congested and high volume traffic areas and one method is focussed on the close-quarters interaction of vessels in port approaches, harbours, and constrained waterways. Some of the methods give only estimate for the collision and grounding probabilities whereas some methods estimate also the consequences of the accidents. According a study reviewed, 8% of examined 400056 AIS messages contained erroneous data. The errors were in MMSI number, IMO number, position, course over ground, speed over ground.
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Summary

Seven collision and grounding risk analysis methods applicable in FSA process are reviewed. Some of the methods are designed to utilize the AIS-data, all of them benefit from it. The reliability of AIS data is also discussed.

Five of the methods can be applied to all sea areas. One method is designed to be applied in congested and high volume traffic areas and one method is focussed on the close-quarters interaction of vessels in port approaches, harbours, and constrained waterways.

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Review of collision and grounding risk analysis methods which can utilize the historical AIS data and traffic patterns in seawaters

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1. Objectives

The objective of this consolidation study is to give a review of the different methods to estimate the collision and grounding risk which can be used in the risk analysis step of the FSA process. Several tools or methods have been developed and most of them are based on the models developed by Fujii [1][2] and Macduff [3]. Some of the methods give only estimate for the collision and grounding probabilities whereas some methods estimate also the consequences of these accidents.

The information obtained from the Automatic Identification System AIS improves significantly the accuracy of the traffic analyses. Some of the collision and grounding risk estimation methods are designed to utilize the AIS-data, however all of them benefit from the better traffic picture it gives.

2. Target stakeholders

The users of the collision and grounding risk analysis methods if they are part of the FSA-process are as follows:

- Maritime administrations and other regulatory decision makers
- Research institutes
- Fairway designers
- Consulting firms
- System developers
- Ship operators

3. Glossary terms

Collision: Ship collision is the structural impact between two ships or one ship and a floating or still objects such as an iceberg or a bridge.

Grounding: Ship grounding is a type of marine accident that involves the impact of a ship on the seabed, resulting in damage of the submerged part of her hull and in particularly the bottom structure, potentially leading to water ingress and compromise of the ship's structural integrity and stability.

AIS: Automatic Identification System

MMSI number: Maritime Mobile Service Identity numbers are nine digit numbers used by maritime digital selective calling (DSC), automatic identification systems (AIS) and certain other equipment to uniquely identify a ship or a coast radio station. MMSIs are regulated and managed internationally by the International Telecommunications Union in Geneva, Switzerland, just as radio call signs are regulated.

4. Approach

The study is based on literature search and on the material collected during performed FSA projects.

5. Specific issues and topics to be addressed

Universities, research institutes and consultancy firms have developed their own collision and grounding risk assessment methods for different purposes. Most of the methods reported here have been developed before the AIS system had reached the position it has today. However, the historical data obtained from the AIS system gives much more accurate traffic picture than traffic analyses based on e.g. port traffic statistics can give thus all the methods benefit from the AIS-system regardless they were developed before or after AIS introduction. In the following, different collision and grounding risk analysis methods have been described.

5.1 Analysis methods

5.1.1 GRACAT

GRACAT (Grounding And Collision Analysis Toolbox) was developed in the Danish Technical University (DTU) in ISESO-project during the years 1998-2001 for analysis of the collisions and groundings in the maritime traffic and the assessment of their risk. The software includes the following modelling characteristics:

- Estimation of the collision and grounding probabilities
- Modelling of the collision and grounding damage
- Estimation of the consequences of the damage

The module for comparison of the calculated consequence costs for different vessels and/or routes and for finding risk control measures.

The different modelling characteristics can be used independently or they can be linked with each other. The damage and their consequences can be analysed either deterministically or stochastically [21][22].

GRACAT uses in the calculation of the collision and grounding probabilities the method which is based on the Fujii's [1][2] and Macduff's [s] models. The conditional causation probability has been calculated by using the Bayesian networks produced with the Hugin software. The structural damage caused by the collisions and groundings is calculated in GRACAT by modelling the external dynamics and the internal mechanics separately [21].

According to Sonninen et al. [23], as a limiting factor in the method used in GRACAT for estimation of the collision probability is the assumption that the time between the arrivals in the traffic flow is distributed independently and exponentially whereas in the normal traffic e.g. in the Gulf of Finland there are traffic peaks in certain days of the week and times of the day.

The GRACAT software has been used in the collision risk estimation of the FSA study performed for the implementation of the VTMS system for the Gulf of Finland [24] and in the risk analysis of the Kõkar fairway plan [25] as well as in the FSA performed for the Western Baltic Sea [26].

5.1.2 BaSSy Tool and IWRAP MAK II

The BaSSy tool is developed by DTU and Gatehouse within the Nordic BaSSy project in 2006-2008. The software is a successor of the GRACAT software (Grounding and Collision Analysis Toolbox), which has been validated in case studies by the developers. The features of the BaSSy tool are also important elements in the ongoing development of the IWRAP Mk2 (IALA Waterway Risk Assessment Program) programme. The approach was the same as presented by Fujii [1][2] and MacDuff [3].

The BaSSy tool takes into account different characteristics of ships such as length, width, speed etc. by categorising ships according to ship type and length. The ship types used are: Crude oil tanker, Oil products tanker, Chemical tanker, Gas tanker, Container

ship, General cargo ship, Bulk carrier, Ro-Ro cargo ship, Passenger ship, Fast ferry, Support ship, Fishing ship, Pleasure boat and Other ship.

The software includes a module which analyses the historical AIS-data recorded on the area considered. As a result of the analysis the route network based on the traffic density plot can be constructed. The routes consist of legs that are defined as straight lines between given waypoints. The number of vessels divided into fourteen ship types and different size categories on each route leg in both directions as well as the lateral distribution of the traffic in the fairway leg can also be achieved.

With respect to ship-to-ship collision situations, the BaSSy tool examines separately five different collision scenarios:

1. Overtaking collision, in which two vessels moving in the same direction collide on a straight leg of a fairway as a result of one overtaking the other
2. Head-on collision, in which two vessels collide on a straight leg of a fairway as a result of two-way traffic on the fairway
3. Crossing collision, in which two vessels using different fairways collide at the fairway crossing
4. Merging collision, in which two vessels using different fairways collide at the merging of the fairways
5. Bend collision, in which two vessels moving in opposite directions on the same fairway collide on a turn of the fairway as a result of one of the vessels neglecting or missing the turn (error of omission) and thus coming into contact with the other vessel

In grounding accidents the scenarios can be separated into four different categories as follows:

1. Ships following the ordinary direct route at normal speed. Accidents in this category are mainly due to human error, but may include ships subject to unexpected problems with the propulsion/steering system that occur in the vicinity of the fixed marine structure or the ground.
2. Ships that failed to change course at a given turning point near the obstacle.
3. Ships taking evasive actions near the obstacle and consequently run aground or collide with the object.

4. All other track patterns than Cat. 1, 2 and 3, for example ships completely out of course due to loss of propulsion.

In determining the grounds and shorelines the software can utilise electronic charts.

As a result the software gives the collision and grounding frequencies for different ship types showing the locations of the predicted accidents on chart.

The BaSSy Tool has been used in the ship to ship collision and grounding analyses performed for the Åland Sea [28]. The estimated accident frequencies coincide quite well with the accident frequencies in that sea area.

5.1.3 MARCS Marine Accident Risk Calculation System [7]

The Marine Accident Risk Calculation System (MARCS) calculates accident frequencies for defined accident types, ship types and size categories, depending on traffic characteristics and environmental conditions in selected areas. The frequency reflects only serious accidents taking place in restricted waters: coastal areas and open sea.

The Marine Accident Risk Calculation System (MARCS) is based upon an analysis of the historical causes of serious marine incidents. This analysis established that the major shipping accidents at sea which may lead to severe consequences are:

- Inter-ship collisions;
- Powered grounding (grounding through navigational error);
- Drift grounding (grounding through mechanical failure);
- Fire and explosions on-board ship (whilst underway – excludes port operations);
- Ship structural failure/foundering.

In general, MARCS calculates accident frequencies (number of accidents per location per year) as the product of the frequency of critical situations (number of critical situations per location per year) and the accident probability, given a critical situation. The number of critical situations per location per year is derived from the traffic image and other data that describes the environment in which the ship trades. The probability of an accident per critical situation is derived from fault trees or aggregated historical statistics.

MARCS assumes that the collision is the consequence of the encounter of two vessels, not of the encounter of the group of several vessels. This may cause that MARCS underestimates the collision frequency in busy sea areas.

MARCS has been applied in the risk analysis of Oslo fjord [8], in the environmental risk analyses of North Sea outside the coast of Belgium [9] as well as in the risk analysis of the Prince William Sound [10][11].

5.1.4 SHIPCOF

The SHIPCOF software developed by Rambøll is aimed to be used in estimation of grounding and collision candidates. It can be applied to accident types caused by human error, critical encounter situation, propulsion or steering system failures. SHIPCOF model is based on the statistical estimation of the occurrence frequencies i.e. on the combination of the geometric and causal probabilities. As the lateral distribution of the traffic in the fairway a combination of uniform and normal distributions is used where 2% of the traffic is following the uniform distribution.

SHIPCOF has been used in the risk analysis of the bridge – tunnel-combination of the Sound. The collision and grounding frequency estimates obtained with the model were quite well in line with the accident statistics registered during 1974 – 1993. However, far outside the fairway the model seemed to underestimate the accident frequency.

5.1.5 SAMSON [14]

SAMSON (Safety Assessment Models for Shipping and Offshore in the North Sea) is developed by the Dutch marine research institute MARIN, with the model various risk assessment calculations can be performed regarding maritime safety. The following types of accidents are contained in the SAMSON-program:

- Collision between sailing ships (head-on, overtaking and crossing);
- Collision of a sailing ship with a ship at anchor (ramming and drifting);
- Stranding / grounding of a ship;
- Contact with objects such as offshore installations, buoys and wind farms (ramming and drifting);
- Foundering of a ship;

- Explosion of fire on board the ship;
- Hull or machine failure.

To determine the frequency of an accident (casualty) occurring, the number of “potential” dangerous situations, the so-called exposures, are determined first. For example, the exposure measure for a collision between sailing ships is an encounter between the ships. An encounter occurs when one ship enters a certain domain around another ship. These exposures are calculated using traffic information, environmental information, some historical information and different (physical based) mathematical models.

The maritime traffic in the model is divided into two main groups: the route-bound and non-route-bound traffic. The route-bound traffic consists of the merchant vessels and ferries sailing along the shortest route from one port to another. The non-route-bound traffic has mainly a mission at sea, containing fishing, supply, work and recreation vessels.

The second and final step in calculating the casualty frequencies, is multiplying the calculated exposures with a casualty rate, corresponding to the accident type to determine the frequency of the actual accident. A casualty rate defines the probability of a potential dangerous situation leading to an actual accident. The casualty rates are based on the worldwide accident data from Lloyds, collected between 1990 and 2002.

5.1.6 MARTRAM

Posford Haskoning's Marine Traffic Risk Assessment Model (MARTRAM) is a modelling tool that is optimised for the analysis of marine risk in areas of congested and high volume marine navigation. MARTRAM is configured to model marine risk, the potential for accidents rather than assessing the level or nature of the hazards associated to the risk. The range of marine risk events considered through the use of MARTRAM cover:

- Ship to ship collision where both are under way
- Ship to ship collision with only one vessel under way
- Ship to ship collision where neither vessel is under way
- Ship collision with another object
- Capsizing, sinking, foundering, fire
- Stranding and grounding

Originally MARTRAM was developed to be used in assessment of the effect of the changes in the Hon Kong Harbour. In addition, it has been used in risk assessment of the effects of the deepening of the channels leading to the Port of Melbourne comparing the current accident frequencies with the estimated frequencies after the channel modifications. [15][16][17]

5.1.7 DYMITRI [18][19][20]

The model is particularly focussed on the close-quarters interaction of vessels in port approaches, harbours, and constrained waterways. Its application, as part of a Quantitative Risk Assessment process, has included:

- Impact of reclamations or bridges by constraining traffic flows
- Review of additional risk developed by introduction of new cargo and passenger vessel movements. These assessments are conducted with respect to specific vessel movements (frequently Dangerous Goods cargoes, such as LNG), and for the waterway as a whole.
- Evaluation of fairway arrangement options
- Safety of construction craft activity in busy traffic lanes
- Impact of wind farm development

Basic approach

- Autonomous agent simulation of marine activity along routes developed from survey data, (AIS or digital radar commonly adopted as inputs).
- Frequency of collision/grounding related to number and nature of avoidance actions.
- Validation of incidents/initiating encounters based on extensive past use of model, and validation against local data.

Approach to the human element

- Fuzzy logic rule based behaviour allows simulation of variable human responses (readily tailored on project specific basis. Inputs into the mariner "brain" are made on the basis of visual sensing of surrounding environment, remote sensing of other shipping activity (to mimic radar / AIS), and perception of bathymetry. All these inputs mimic the inputs available to the human mariner, and can be varied to suit low visibility conditions, etc.

Input needed

- Physical Environment
 - Bathymmetry & Features (Most conveniently developed from ENC charts which are translated into GIS format)
 - Metocean Environment (wind/wave/currents, to identify if these aspects should be particularly included in model)
- Traffic network (vessel distribution, speed, timing, type)
- Traffic density per network link, per ship type and size class
- Background information on local developments and port economic drivers to assist the preparation of forecasts for future case scenarios
- Casualty rate (collisions and groundings) for the Study Area

Output provided

- Probability of grounding/collision incidents per cell
- Delays, and other operational data. For example the model can include ships picking up passengers/cargo during operations and the total volume of passengers/cargo transported can be output via tailored subroutines.

Graphical output

- Animation (3D) of vessel movements and interaction
- GIS representation of key incident data distribution, i.e. magnitude as frequency per cell per annum.
- All input/output to/from the model is processed via an ArcGIS interface for ready QA/visualisation of inputs and representation of outputs.

Validation of model results

- Project based validation of model conducted for over 30 risk assessments conducted in Hong Kong, Singapore, Korea, and the English Channel. In general a Study Area specific validation is conducted prior to the use of the model on a forecast basis.
- Over 30 commercial studies since 2000 conducted principally in Asia associated with the QRA of marine safety as a result of increased traffic and/or reduction/realignment of waterways.

5.2 AIS data

The implementation of the AIS system has significantly improved the accuracy of the traffic analyses in the FSA studies. Every ship more than 300 gross tonnes engaged on international voyages, cargo ships over 500 gross tonnes not engaged on international voyages and all passenger ships should have equipped with AIS. The data used in the FSAs is recorded historical AIS data covering the target sea area.

5.2.1 Sources

The AIS data can be obtained from several sources. There are commercial AIS networks collecting the traffic data and providing different services to customers. In the Baltic Sea the HELCOM AIS monitoring system has been established [30]:

- a passive system, i.e. enables access to AIS data, for example real time AIS data
- each country may filter the AIS data according to national requirements
- only competent authorities shall have access to the system.

The system enables the identification of the name, position, course, speed, draught and cargo of every ship of more than 300 gross tonnes sailing in the Baltic Sea, and displays all the available data over a common background map of the region. The system covers the whole of the Baltic Sea and Norwegian waters. The system includes land-based stations established in all the coastal countries to receive information from all vessels passing through their national waters. All stations are linked to a special "HELCOM server", which combines all the data and provides a comprehensive real-time picture of the overall maritime traffic situation in the Baltic Sea to the competent authorities in each HELCOM member state. The server updates ships' positions every six minutes.

5.2.2 AIS data quality

The AIS data may contain errors which are either intentional or unintentional. The errors are reported in the article published in The Journal of Navigation [29] in which results of three separate studies of AIS data are reported: "VTS-based AIS study", "Data-mining AIS study" and "Proactive AIS study".

In the "VTS-based AIS study", 94 vessels were investigated and in 18% of the vessels there were incorrect ship beam value, in 47% incorrect ship length value, in 30%

incorrect navigational status and in 74% incorrect vessel type information entered in the installation of the AIS equipment.

In the “Data-mining AIS study” about 8% of 400 059 analysed AIS reports contained some errors. The study concentrated on errors in Maritime Mobile Service Identity (MMSI) number, IMO number, position, course over ground (COG), and speed over ground (SOG).

In risk analyses, usually the following data items from the AIS information are utilised:

- MMSI number (errors may cause wrong ship types if the ship type is obtained from the Lloyds database using the MMSI number)
- ship length and beam (errors may cause wrong values in quantities which have to be calculated as a function of the ship dimensions)
- position data (errors may cause wrong estimates of the collision and grounding frequencies)
- draught data (errors may cause wrong estimates of the grounding frequencies).

Methods to check the quality of the AIS data and clean up the identified errors and disturbances have been developed and they should be utilised before using the AIS data in risk analyses.

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