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Determining Collision Risks for Fixed Offshore Constructions

John C. Bandas [1] (AM), **Yvonne Koldenhof** [2] (V), **Thomas J. Sellers** [1] (V)
[1] Maritime Research Institute Netherlands (MARIN) USA, Houston, Texas
[2] Maritime Research Institute Netherlands (MARIN), Wageningen, The Netherlands

To determine the risk involved in operations around offshore structures, static and dynamic traffic models can be used to assess the individual probabilities of incidents. This paper describes the underlying models to determine ramming (powered) as well as drifting collision frequencies for fixed objects at sea based on static traffic databases or AIS data. Static representations of the traffic allows for different risk models and accident statistics in determining the frequency of collision of a fixed object. AIS data, which shows the actual paths sailed by ships, can replace this static traffic database by a more dynamic risk model. As an example, this paper describes the approach for the risk assessment of an existing and future offshore installation.

KEY WORDS: Ramming Collision Frequencies; Drifting Collision Frequencies; Offshore Platform; Offshore Wind Turbines; AIS; Maritime Risk Assessment

NOMENCLATURE

AIS = Automatic Identification System

FSA = Formal Safety Assessment

GT = Gross Tonnage

m = meter

MSP = Marine Spatial Planning

SAMSON = Safety Assessment Model for Shipping and Offshore in the North Sea

SAR = Search and Rescue

EEZ = Exclusive economic zone

IMO = International Maritime Organization

PIANC = Permanent International Commission for Navigation Congresses

INTRODUCTION

The combination of less available space, increased shipping traffic, and additional objects (wind farms, platforms, fish farms, etc.) increases the probability of incidents for offshore installations. Organizations like IMO (International Maritime Organization), the Nautical Institute, PIANC, and the World Ocean Council are calling for risk assessment studies to be applied when assessing changes to areas with shipping lanes and traffic. Procedures such as FSA (Formal Safety Assessment) and MSP (Marine Spatial Planning) should be used when studying installations and maritime activities, to reduce the risk of accidents including collisions, spills, groundings and other damage caused by marine activities. Planning of marine installations and activities without applying risk assessment studies will lead to unanticipated consequences such as accidents, environmental damage or commercial losses. Considerations for the type of maritime activity, traffic density, maneuverability of the operating vessels, characteristics of the area, navigational aids, design of shipping channels, etc. must all be taken in to account.

In this paper, static and dynamic risk assessment methods are described. The difference between the methods lies in the applied traffic database. A case study presents the static approach for analyzing either an existing or future offshore installation, with consideration for adding the dynamic approach.

The SAMSON model (Safety Assessment Model for Shipping and Offshore on the North Sea) is a safety assessment model that can be used to determine the frequencies and consequences of different types of nautical accidents in a certain sea area. This model uses a static traffic database, consisting of nodes and links, to model the traffic. Created in 1975, the tool has been designed for the North Sea, but can and has been applied to many other areas to determine the frequency of collisions. The advantage of using a more static representation of the traffic patterns is that these patterns can be altered to represent future situation, e.g. new wind farm location or relocation of offshore platforms.

The Automatic Identification System (AIS), showing the actual paths sailed by ships, can replace the “static” traffic database with a dynamic risk model. This way, the modelling of the traffic can be improved, particularly for less dense areas outside of the main shipping lanes. In the method using AIS, the collision risk for the offshore installation is calculated for every time step using the same existing modules of the SAMSON model, but now applied to a dynamic traffic database

The current method with AIS traffic data has already been used in different studies such as the BE-AWARE project (EU-funded), and in various collision risk studies for offshore platforms and planned wind farms on the North Sea.

Historically, the SAFE-SHIP project catalogued the technical and organizational measures for reducing ship collision risks for deeper water depths of 20-25m in the Dutch EEZ part of the North Sea (den Boon et al. 2003 and 2004). The deeper water, presence of dense shipping lanes, and presence of other offshore platforms introduced risks of collisions with larger ships, which leads to different effects on the wind turbine than collisions with smaller ships.

One study of LNG operations (Maseda et al., 2004) used SAMSON in combination with fast- and real-time simulations to train and familiarize operational personnel. For these type of tow and offloading operations, the risk model not only provided input for mitigating grounding and collision risk, but also gave an indication of waiting time and the availability of tugs. Another study combined the SAMSON model with an analytical collision model MARCOL to determine the specific risk of LNG cargo collisions such as tank penetration (Ligteringen et al., 2007).

AIS was used in risk collision in (Koldenhof et al, 2009) for integration in a wider Maritime Operational Services (MOS) center in Milford Haven, Wales. With SAMSON, operators used the risk approach combined with the monitored AIS data to identify high-risk ships. The MOS center could then use mitigating measures more effectively than with a basic risk methodology.

This method was further used for a risk assessment in the port of Rotterdam (Tak et al., 2012). A regression analysis was performed in order to classify the traffic characteristics. This model yielded dynamic parameters to apply in SAMSON, and the method was able to be used practically in real-time collision risk analysis of a specific location and ship.

The SAMSON model was also used in a pilot study to determine the frequency of spills in Canadian waters (Creber et al., 2017). The resulting probability of different oil spill volume types was validated with available marine accident data. The pilot areas showed a reasonable estimate of the risks of shipping accidents, but are being followed up with a more detailed review of historical AIS data.

Formal Safety Assessment Requirements

The study follows in part the Formal Safety Assessment methodology (IMO 2020). The flow chart, shown in Figure 1, describes the steps used within an FSA. The strength of the method is that risks that are not clearly visible in a quantitative analysis are identified in an expert session. In turn, the quantitative analysis helps to objectify the risks that emerge from the expert sessions.

The steps within the FSA are explained below in a short example for the hazard type “propulsion of a recreational ship (sailing yacht) with a wind turbine”:

- Relevant failures, causes and consequences are identified and assessed in expert sessions. A possible hazard could be the propulsion of a recreational vessel into the wind turbine.
- The initial risk level is calculated by combining the hazard identification in step 1 with SAMSON. In this example, the question is answered: “How many sailing yachts hit wind turbines per year and what is the consequence?”
- A second expert discusses how to manage this risk: “How could we prevent the wind turbine collision? What resources do we have to rescue the passengers and the yacht?”
- The cost effectiveness of the risk management is analysed: “What will we save if fewer yachts hit wind turbines?”
- Policy recommendations are made for nautical management, beacons and lighting, rescue capacity, etc.

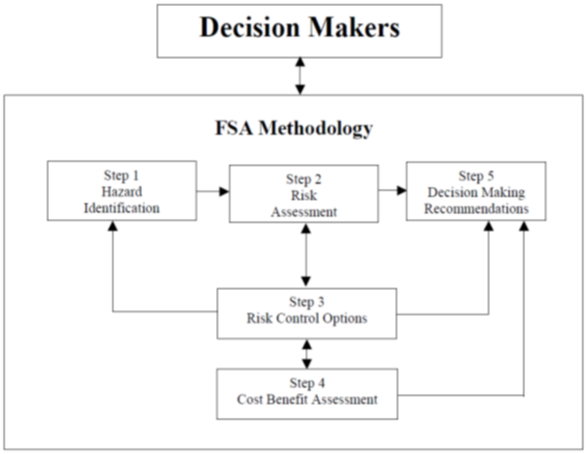

Fig. 1: Flowchart Formal Safety Assessment

APPLIED SOFTWARE MODEL

SAMSON Model

The SAMSON model can be applied to many types of marine risk assessment studies, for example: vessel collision, offshore installation collision, risk to buried cables or pipelines, risk to terminals, risk to moored vessels, etc. The model has been developed, validated and improved over the past 30 years. A system diagram of the SAMSON model is shown in Figure 2.

The “traffic demand”, “existing management systems”, “tactics”, and “contingency planning” depend partly on expert panel evaluations for the site being examined. The present paper ignores these aspects to focus on the accident probabilities and impacts.

Different accident models are used to determine the accident frequencies based on the complete traffic image. In addition to accidents due to traffic, there is a probability of an accident due to local undersea pipes, and a probability of onboard accidents such as fire. The mathematical model for accident frequency uses accident statistics, area conditions, and navigational aids as input.

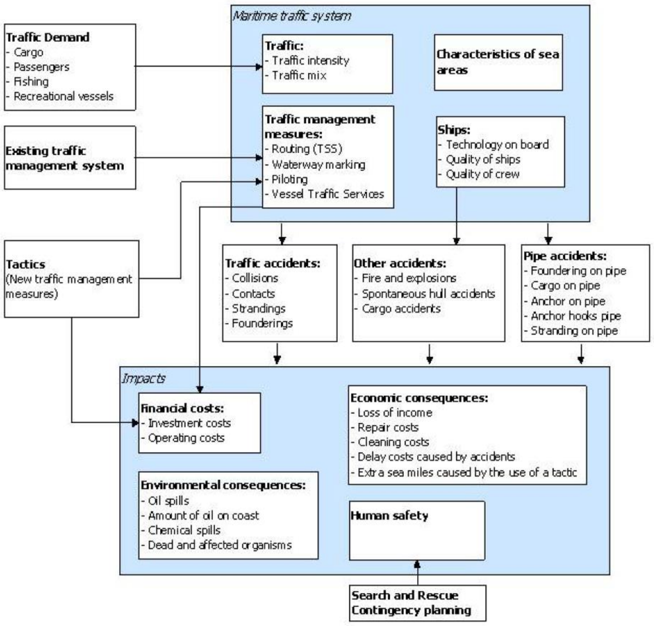

Fig. 2: System diagram for the SAMSON model

An overview of the calculation of the incident frequencies is shown in Figure 3. The model parameters have been obtained from the worldwide casualty database of 1990-2014 of Lloyd's' Register Fairplay. In addition, more recent traffic databases have been developed through projects such as BE-AWARE and various project for the Dutch RijksWaterstaat..

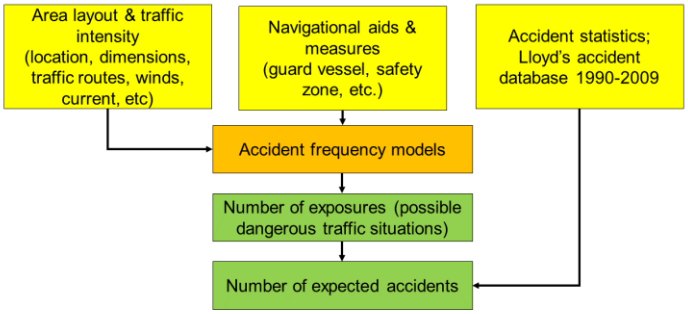

Fig. 3: Overview calculation of incident frequencies

Traffic Databases

The "Maritime traffic system" block in Fig. 2 contains four sub blocks that describe the complete traffic pattern: the number of ship movements, the existing traffic management systems, the characteristics of the ships and the layout of the sea area.

An important input for the modeling is a good description of the traffic. This description is largely based on AIS data, translated into a traffic database. SAMSON uses a traffic database that describes the density, composition and behavior of marine traffic. The maritime traffic is divided into two main groups: route-bound ships and the non-route-bound (random) ships. Route-bound traffic is typically composed of merchant vessels and ferries sailing along the shortest route between ports, whereas non-route-bound traffic contains vessels that mainly have a mission at sea, such as fishing vessels, supply vessels, working vessels and pleasure crafts. The SAMSON model handles these traffic types in a different manner to assess the posed risk.

Due to the location of different ports and traffic separation schemes, most route bound ships sail on a network of links (connection between waypoints), comparable with a road network. The intensity for an area gives the number of vessels per year which follow a certain link divided over ship type and ship size. A link characteristic defines the width and the lateral distribution of the traffic over the link. When all rules are followed, the network of links contains the shortest routes between ports.

Non-route-bound traffic cannot be modelled the same way as route-bound traffic, due to its random behavior. A non-route-bound ship does not sail from port A to port B along a defined route, but rather from port A to one or more destinations at sea and then usually back to the port of departure, port A. Fishing vessels account for the largest group of the non-route-bound traffic and they usually sail from one fishing ground to another during one journey. For this reason, the behavior of these ships at sea is much harder to predict than the behavior of the route-bound vessels. Therefore, the traffic image of non-route-bound traffic is modelled by densities of ships in so called grid cells.

Contact Model

SAMSON contains a number of models to determine the probability of a marine collision or damage event that is caused by an initial event on board a ship. For each type of event, a model has been developed that can assess the frequencies of occurrence. Threat models include the frequencies of all events that can lead to collisions for example the probability of black out, rudder lock, engine loss, cargo loss, vessel sinking, anchor dropped on undersea structure, among other events.

The ship-contact model is used to assess the threat of a vessel colliding with a ship and fixed offshore installation such as a platform, wind turbine or moored vessel. The fixed objects are modelled either as rectangles or circular shapes, depending on the actual shape of the platform. Wind turbines are modelled in a similar way, where each turbine is a separate platform with a circular shape and diameter.

In the SAMSON-model, two types of collisions with an object are distinguished: ramming and drifting collisions. Both are shortly described below:

- A ramming collision occurs when a ship, during normal operation, is on a collision course with a platform and then a navigational error occurs. This error is not detected until after the point of no return, and then the ship collides with the platform. The collision may be at high or low speed depending on the time lapse between the point of no return and the implementation of a corrective action after the detection of the error.

- A drifting collision occurs when a ship in the vicinity of a platform/rig experiences a failure in the propulsion engine or in the steering equipment. Since the ship slowly becomes uncontrollable as it loses speed, the combined effect of wind, waves and current may carry it towards the platform. This is illustrated in Fig. 4. If dropping anchor does not help or is not practical and the repair time exceeds the available time, the ship may collide against the platform/rig. Drifting collisions generally happen at a low speed.

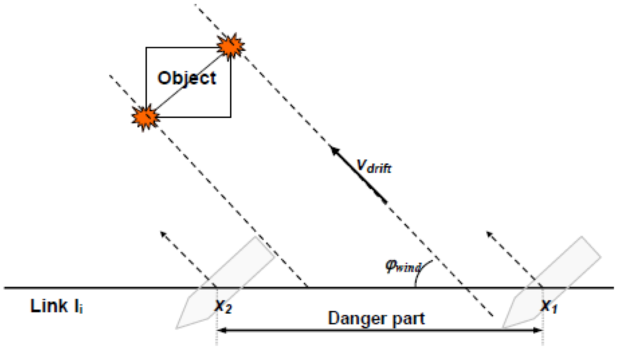

Fig. 4: Illustration of drifting contact model

A passing vessel poses a threat to a fixed object only for part of its passage, the so-called "danger-miles". Ramming and drifting collisions have different dangerous parts of the passages. For example, a drifting collision is possible in the part of the passage in which the vessel could drift against the object in case of an engine failure, given a certain wind and current condition (see Fig. 4).

The total of these "danger miles" is then multiplied with the probability that "something" goes wrong (the initial event). For drifting, this is the probability of an engine failure per sailed mile.

To obtain the collision probabilities, the calculations are done for a variation of wind and current conditions. A reduction factor is also applied to account for the probability of "engine repair" or anchor intervention.

The probability of ramming is linked to human error by the watch keeping officer on board a vessel. In the SAMSON model, this is modeled by using general collision data, not specifically for wind farms, because the collision data specifically for wind farms is not known.

More detail on the formulae for the probability of contact can be found in the report of the BE-AWARE project (van der Tak et al., 2014).

Description of the Dynamic Risk Model with AIS

Since 2005, all ships above 300GT are obliged to have an AIS transponder turned on at all times. The transponder sends an automatic message several times a minute via a VHF transceiver. The AIS data is combined with modules of the SAMSON model: instead of using fixed waypoints and nodes, the actual vessel positions are used. Using AIS data, the traffic around existing offshore installations can be modelled accurately. For small time steps, the accident frequencies for all ships present in the proximity of an offshore installation is determined by modelling the ships at their actual location and with their actual speed over ground and course over ground. Furthermore, specific casualty rates for each ship can be determined, based on parameters such as the ship type, size, age and flag.

A schematic overview of the calculations is provided in Fig. 5. Several vessels are shown (small dots with an oval line around it): the black lines indicate the sailing direction, and the length of this line represents their sailing speed. The orange dotted arrow indicates the possible threat for a given platform location.

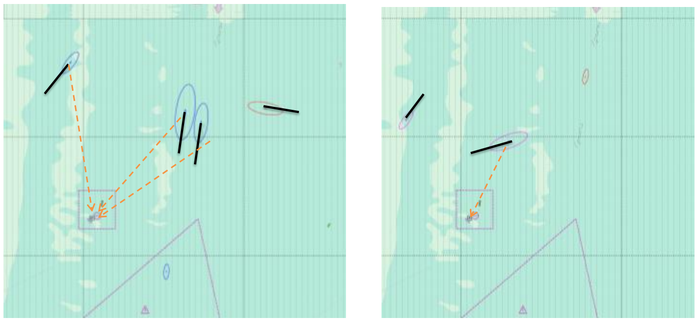

Fig. 5 AIS-data of a passing vessel

The collection of these vessels and their passages form the "traffic database" that is used to calculate the collision frequency at each time step. The frequencies for each time step are summed for a year to determine the annual collision frequencies.

Consequences of a Contact with a Fixed Object

In addition to the frequencies of a collision, the SAMSON model also looks at the consequences, by determining the expected available energy on impact. The vessel could simply drift into the platform, buckle the platform at the water line or seabed, or shift the foundation and tilt the whole platform (illustrated in Fig. 6).

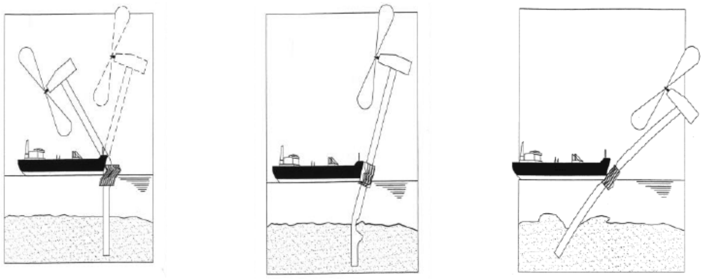

Fig. 6 Illustration of buckling and bending types due to ramming collision

The collision frequency per year is divided over a number of kinetic energy classes, to distinguish collisions with high and low impact energy. The kinetic energy for the ramming and drifting collision used in the calculations is the worst-case energy value as if the contact with the platform or rig takes place in the direction of the movement of the center of gravity of the ship. This is conservative:

- For ramming, a platform/rig is not always hit frontally. As a result, a part of the energy may not have to be resisted by the platform;
- For drifting, the first contact point can be spread over the whole length of the ship. The impact energy only approaches the energy value from the calculations when the first contact point lies near the middle of the ship.

WIND FARM CASE STUDY

Introduction Case study

The collision risk is calculated for a project of 1,144 wind turbines in the Dutch Exclusive Economic Zone (EEZ) in the North Sea, and described in this section. With the current AIS data from 2017, there are 289 wind turbines existing.

The North Sea is one of the most densely populated sea areas in the world, with a very dynamic traffic situation. The construction of offshore wind farms and the expected growth in ship movements will further increase the intensity for traffic and installations in the area. The combination of less available space, increased traffic and additional objects (wind turbines) in the area increases the probability of incidents. The construction and maintenance of wind turbines will also affect the construction and maintenance vessel traffic in the area. Generally there will be more deviant traffic behavior which will effect shipping safety, traffic flow and accessibility to ports. The Dutch government's policy is to maintain the present shipping safety levels in the Netherlands sector of the North Sea. In order to meet this policy, an FSA has been performed to assess the effect of the construction of all planned wind farms till 2030.

The risk assessment was done both in a qualitative manner (through different expert sessions) and in a quantitative manner (using the SAMSON model). In addition to the risk assessment of the wind farms, different risk control options were considered, with recommendations on managing any indirect risks due to the presence of the wind farm.

The subsequent sections of this paper focus on results from SAMSON, with expert session conclusions excluded.

Risk Definitions

The construction of a wind farm at a certain location introduces new risks to existing traffic, broadly defined in two categories: indirect and direct risks.

Indirect risks are those that result from rerouting of the traffic. Most of the wind farm areas are closed for other traffic, or at least for certain types of traffic. This means that vessels have to take a different route, and could increase the traffic density in other locations. Therefore, the expected number of ship-ship collisions could also increase. Particularly, the interaction between larger and smaller vessels in the area—the smaller vessels travelling between the wind farm and the main shipping lanes—could lead to a more complex traffic situation. The traffic intensity of existing offshore constructions nearby (such as platforms) could change, leading to a change in the collision risk of these objects, either in a positive or negative way.

Direct risks are more straightforward: the accident frequencies increase due to the new fixed objects in the area. This includes the collision frequencies of the wind turbines discussed in the previous section, and the resulting consequences of these collisions.

Using Static vs Dynamic Methods

The risks are quantified using SAMSON. In this case, the SAMSON model was used and not the "Dynamic risk model using AIS". This is because the dynamic model requires the AIS data including the fixed objects: since the wind turbines are not installed yet, the current AIS data will not accurately reflect the traffic at the end of construction. To determine the future traffic situation, it is easier to use the "static" representation of the traffic, with nodes and links. These nodes and links can be altered to reroute the traffic and also the intensity on the links can be changed to represent a future traffic scenario.

However, the AIS-data is still useful to create the initial "static" traffic database which is used in the SAMSON model.

Description of Shipping Traffic

To determine the indirect and the direct risks of the wind farms, a good description of the traffic is essential. Three scenarios for the present and future traffic were identified:

- "T0 scenario": current situation, traffic intensity based on 2017 and only the existing wind turbines and offshore platforms
- "T1 scenario": situation before 2030 without the construction of additional wind turbines. The traffic intensity has been adjusted based on the growth factors. The route structure has not been adjusted.
- "T2 scenario": situation before 2030, with the additional wind turbines. The traffic intensity has been adjusted based on the growth factors. The route structure has been adjusted in two ways to steer the routes "around" the parks. Additional work traffic has also been added to the non-route-bound traffic database.

For the current scenario, the traffic database for the route bound traffic was built up using AIS-data from 2017. The first step in building up the traffic database is creating density charts (Fig. 7) where ships are broken down by category. In the current scenario, the location of the existing 289 turbines are known, and included in the analysis.

The second step is defining the location of the nodes and links of the traffic database and assigning the different vessels to these links from the AIS. A route structure can then be "drawn" using the traffic data compiled from AIS.

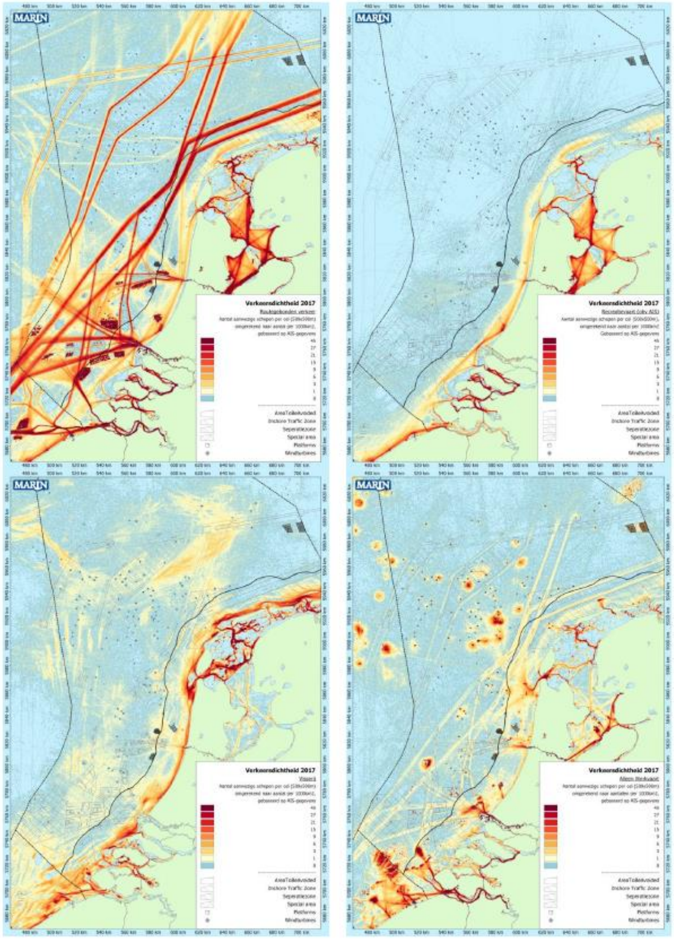

Fig. 7 Density map, 2017, by vessel type. Top left: route-bound traffic; top right: recreational shipping (based on AIS); bottom right: commercial shipping

An example of the route structure is shown in Fig. 8. Considering the COG (Course over Ground) and the distance to a route line, an AIS target is assigned to a particular line. The number of passages per vessel type and vessel size can then be determined for each part of the route structure. This number of passages forms the basis for the traffic database for the 2017 scenario.

The third step is to create the different traffic databases representing the different future situations. In this case, the traffic database was created for the year 2030, without the extra wind farms, so only applying the expected autonomous growth (Streng 2018) and the increase in ship size and intensity. A second scenario was created for 2030 including the build of the wind farms, assuming an expected autonomous growth and subsequent rerouting of some parts of the traffic.

The "T2 scenario" assumed 1,144 extra turbines in the calculation. Only some of the planned parks in 2030 have exact positions of individual turbines known. Therefore, the model distributed the unknown turbines evenly over the entire surface of the designated areas.

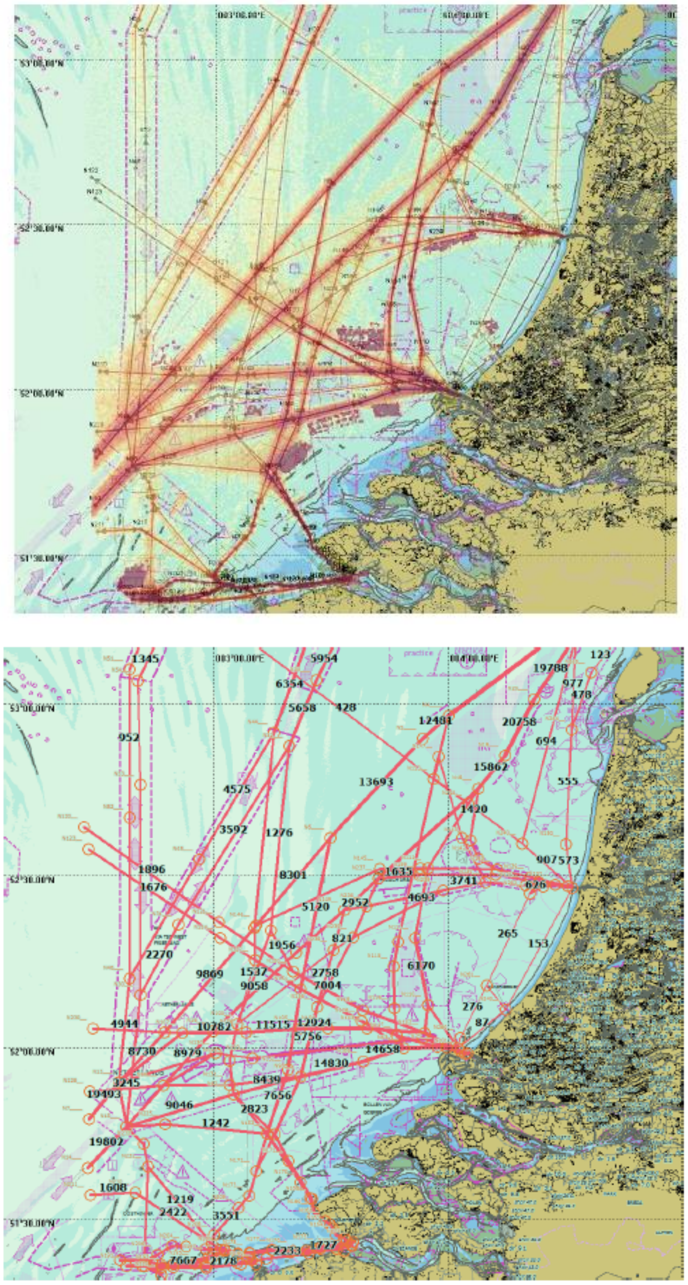

Fig. 8 Top: Traffic database for route-bound traffic with route structure, Hollandse Kust Bottom: Traffic database for 2017 (black number of passages in one direction)

Non-route-bound traffic (fishing, supply shipping, work shipping and recreational shipping) is modeled in a different manner, as the behavior of this traffic at sea is different. Since the behavior of non-route-bound traffic at sea is basically unpredictable; this traffic is modeled by means of densities in SAMSON. The average density is discretized into grid cells, whose size is based on AIS data for these categories of ships.

The result is a non-route-related traffic database as shown on the left in Fig. 9. On the left the increase in traffic is clearly visible from 2017 to 2030. On the right, the shift of the routes around

Borssele and IJmuiden. In addition, the “narrowing” of the waterways is also slightly visible. Existing traffic that is not allowed to sail in the wind farm is moved to a grid cell just outside the park. In this way, the indirectly increased traffic density is accounted for.

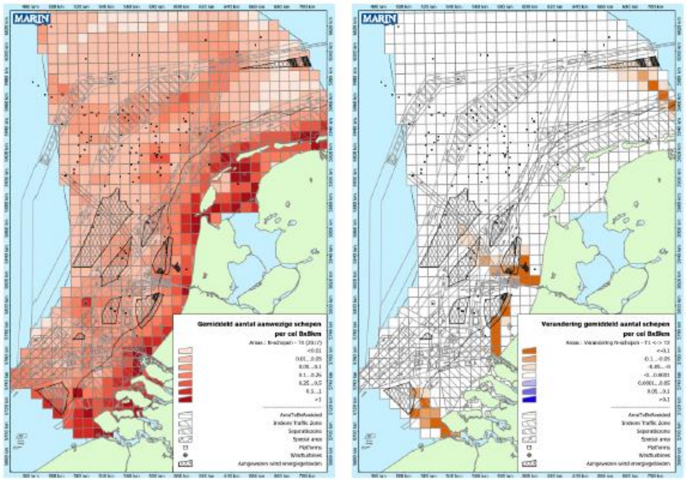

Fig. 9 Left: Number of non-route bound ships per grid cell (8x8km) for 2030 situation. On the right the change in the number of non-route bound ships present in 2030 with the build of the wind farms (orange color is increased)

Extra working vessels sailing between the coast and the wind farms during installation and maintenance phases were added to the traffic database (see Fig. 10). The wind farms can be seen as the grey regions in the map. The traffic intensity in these phases are based on the number of expected turbines and the number of visits found in the current monitoring of the existing wind farms.

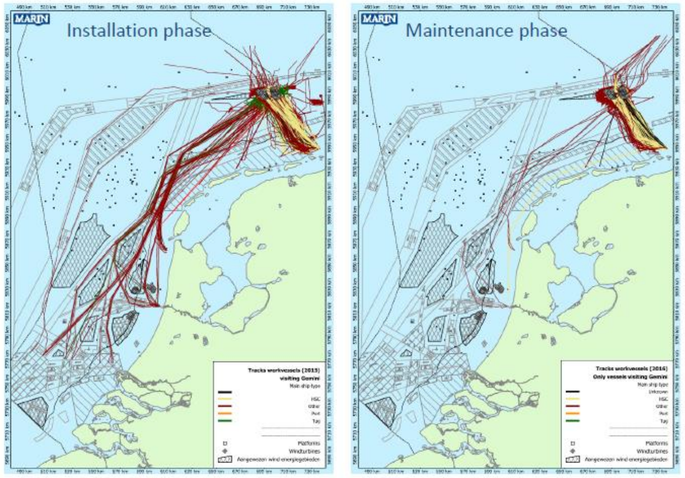

Fig. 10 Effect of installation and maintenance phases on traffic density

The results of this analysis are used to determine the expected number of extra vessel movements per turbine in the different phases. It was assumed that the intensity and location of the fishing industry remains the same in 2030, as well as the shipping industry (Streng, 2018). The study does not take into account the presence of submerged cables or pipelines.

Results of SAMSON Model

The probability of a collision between ships, a contact with an existing offshore platform, and a contact with a wind turbine was determined using SAMSON.

The expected number of collisions between ships annually is calculated, and given in Table 1. It can be seen that work vessels are often involved in collisions, and the increased traffic regardless of wind farm construction significantly increases the number of collisions with route-bound traffic.

Table 1. Number of expected ship-ship collisions per growth scenario and ship type

Ship type	Number of collisions per year		
	2017	2030 w/o wind farms	2030 w/ wind farms
Cargo	1.53	1.95	2.01
Tanker	1.13	1.46	1.48
Passenger	0.35	0.45	0.46
Fishing	0.49	0.51	0.52
Work vessels	3.36	3.43	3.52
Recreation	0.27	0.28	0.28
Total (per year)	7.13	8.07	8.27

The total number of collisions for existing offshore platforms in the Dutch part of the North Sea is calculated in Table 2. The total number of collisions increases to once every 3.5 years, not due to the construction of the wind farms, but due to the expected increase in traffic intensity.

Table 2. Number of expected ship to existing offshore platform collisions per growth scenario and ship type

Ship type	Number of collisions per year		
	2017	2030 w/o wind farms	2030 w/ wind farms
Cargo	0.0513	0.0576	0.0576
Tanker	0.0259	0.0296	0.0296
Passenger	0.0114	0.0129	0.0129
Fishing	0.1390	0.1390	0.1390
Work vessels	0.044	0.0441	0.0447
Recreation	0.0018	0.0018	0.0018
Total	0.2735	0.2850	0.2857
Once per… years	3.7	3.5	3.5

No demolitions of old platforms is considered: this would decrease the risk of incidents between ships and platforms. It is noted that fishing vessels have a relatively higher risk of colliding with the platforms, as they sail more often in the vicinity of the platforms.

In addition to the existing offshore platforms, the risk of collision with the existing wind farms in the North Sea are shown in Table 3. The increase in the number of wind turbines from 287 to 1,444 leads to much higher chances of collision, to once every 0.7 years. Non-route-bound traffic (fishing and work vessels) contribute significantly to the risk of collision. In the study, it was found that most of these collisions are “ramming” type collisions, as opposed to “drifting”. Crews sailing in the wind farm should be trained and aware of the risks in the presence of the turbines. However, it is possible that the vessels may get used to the risk and make a navigational error. More data on ship behavior in the wind farms is necessary, but currently the results are assumed to be a reasonable estimate of the risk.

Table 3. Number of expected ship to existing wind farm collisions per growth scenario and ship type

Ship type	Number of collisions per year		
	2017	2030 w/o wind farms	2030 w/ wind farms
Cargo	0.0204	0.0234	0.1720
Tanker	0.0110	0.0126	0.1021
Passenger	0.0069	0.0079	0.0689
Fishing	0.0191	0.0191	0.7413
Work vessels	0.0274	0.0274	0.3301
Recreation	0.0010	0.0010	0.0178
Total	0.0858	0.0913	1.4321
Once per… years	11.7	11	0.7

In Table 4, the allowed vessel length limit for non-route-bound traffic is varied from 24m to 80m to adjust the traffic intensity, and calculate the difference in ship collision probabilities. Because recreational craft are usually smaller than 24m, the density of this type of ship traffic is unaffected.

Table 4. Effect of passage scenarios on total annual incidents

Incident type	24m	45m	80m
	[1/year]		
Collision between ships	8.27	8.25	8.24
Collision with wind turbines	1.43	1.87	2.05

With larger passage lengths, the number of collisions between ships decreases slightly, but the number of collisions with wind turbines increases as larger ships are allowed to leave the shipping routes and enter the wind farms. 24m ships are considered by the qualitative analysis to have a relatively low impact, while 80m vessels would cause major damage in an incident; the consequences of collisions with 45m vessels is unknown, and requires further study.

In Table 5, the main results are summarized. For the 2017 scenario, the number of expected ship-ship collisions in the Dutch EEZ is 7.13 per year. The number will automatically increase to 8.07 in 2030 (without any wind farms): this is due to the expected increase of shipping intensity in this area. The expected number with the constructed wind farms will be 8.27 per year. This is just a small increase due to some changes in traffic routes.

Table 5. Number of expected collisions between ships for T0, T1, and T2 by ship type

Accident type	Summary collision probability results [1/year]		
	2017	2030 w/o wind farms	2030 w/ wind farms
Collision between ships	7.13	8.07	8.27
Ship to platform collision	0.274	0.285	0.286
Ship to wind turbine collision	0.0857	0.0913	1.432
Total	7.490	8.446	9.988

The main increase in expected accidents can be found in the expected contact frequencies with a wind turbine. This will increase from 0.0857 per year in 2017 (with 289 turbines built) to 1.432 per year (with 1,144 turbines built in 2030).

The contact frequencies are calculated per individual wind turbine. Fig 11 shows an example of the output from the calculations for a specific wind farm location. By calculating the contact frequencies per wind turbine, the results also provide information of the turbines with the highest contact risk. It can be seen that the location of the turbine drastically affects the risk for that particular structure. It is also seen that the larger the number of turbines, the greater the overall risk. Spatial planning can be used when searching for the most effective mitigation measures.

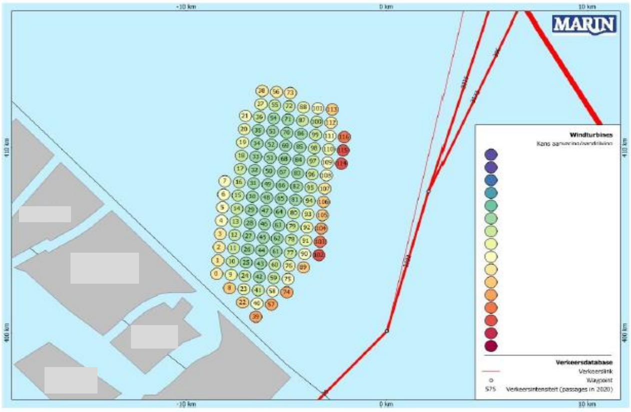

Fig. 11 Risk assessment of individual turbines in farm

Consequences of Collisions between Ships

The previous analysis only looked at the likelihood of a collision between ships. It did not consider the expected frequency of oil/chemical outflows, or the number of expected deaths/injuries as a result of the collisions. This frequency has not been determined at this stage of the study. Therefore, the consequences resulting from collisions between ships are assumed to only depend on the number of expected accidents themselves. There is no prediction of greater or lesser growth for oil tankers or chemical tankers, which could lead to an additional increase or decrease in the risk of environmental pollution (Streng 2018). No abnormal growth is predicted for passenger ships, either; the fleet composition does not change very much in the different scenarios. It is assumed that the likelihood of oil outflow and risk to individuals will increase simply in proportion to the number of collisions expected. The wind farms only directly affect the fleet composition by increasing the number of work vessels.

Consequences of a Contact with a Wind Turbine

The consequences of a collision with a wind turbine specifically (as opposed to other types of offshore platforms) have not been quantified using SAMSON. In previous studies, a damage matrix was used to determine the consequences. However, this matrix is partly based on a publication from 2000 (EU-project SAFESHIP) and has been determined for smaller turbines and piles. Due to the increase in scale of the windmills, as well as the drift properties of ships with very large windage areas (such as ultra-large cruise and container ships), the consequences could be larger than assumed. It is recommended to conduct more research on the consequences of a collision with a turbine, where not only the damage to the wind turbine is important, but also the damage to the ship, which in turn could lead to oil pollution or fatalities / injuries.

NOTES ON QUALITATIVE ANALYSIS

Although the paper only discusses the quantitative analysis, the study for this project—and for similar studies—is a combination of quantitative and qualitative analyses. The qualitative analysis is mainly focused on nautical management measures, which depends on expert sessions that are unique to each location. For example, small adjustments to even the individual wind farm turbine locations could significantly affect the occurrence and consequences of collision. These types of measures on future wind farms cannot be quantitatively estimated, and therefore are outside the objective of the paper to present the quantitative analysis method.

In general, however, three “risk areas” were distinguished by the expert sessions:

- The main shipping routes
- The buffer zones between the shipping routes and wind farm safety zone
- The wind farm safety zone

The risks in these zones are quantified in SAMSON, and then the expert session meets again to discuss mitigating measures and their cost effectiveness.

Some mitigating measures proposed by the expert session include specifying a minimum distance for ultra-large ships to maneuver and anchor, to reduce the risk of drifting collision. If a ship has a large enough deck to actually touch a rotating windmill blade, extreme caution should be taken maneuvering around the wind farms. The coverage of AIS beacons for platforms and ships operating in the area should be sufficient to identify high-risk situations, and also lend data to further analyses towards 2030. The effect of bottom fishing should be investigated further, to determine the extent of cable protection required. Finally, the risks of collision should be made clear to local recreational sailing.

CONCLUSIONS

The SAMSON model can be used to determine the accident frequencies for fixed objects such as platforms and wind turbines. Direct effects from these structures can be calculated due to the introduction of new collision risks, as well as the indirect effects of the installation area due to traffic rerouting.

The contact frequencies for an existing fixed object such as a platform or a wind turbine are calculated, using a new method that applies AIS-data as input for the risk models. By using the AIS-data, the real traffic behavior surrounding the object is taken into account, thereby providing a better representation of the actual situation and risks.

To predict the nautical accident frequencies for future scenarios, the more “static” representation of the traffic using nodes and links is (for now) the best method. This approach provides the opportunity to modify routes and respective traffic intensities.

The static method was used in the Netherlands to assess the effects of a proposed wind farm consisting of approximately 1,144 wind turbines on the Dutch EEZ of the North Sea. Both a quantitative analysis and initial qualitative analysis was performed for this wind farm; however, the qualitative analysis needs to be updated as the wind farm develops, so the paper focuses on the quantitative methods.

Three different traffic growth scenarios were examined in the quantitative analysis. The number of collisions between ships increases both due to natural growth in traffic and the presence of the wind farms, while the number of collisions with turbines increases as larger and more ships operate in the vicinity. Allowing larger ships to leave the main shipping routes can slightly decrease ship-to-ship risks, but increases the risks between vessels and wind turbines.

FUTURE WORK

More work needs to be done to determine the consequences of a collision with a fixed object, especially a wind turbine. Therefore, it is important not only to look at the consequences for the wind turbine, but also to the possible damage to the colliding vessel.

The final consequences, such as the risk for people on board or a possible outflow of oil are important factors when assessing incident risks.

In the current methods, the contact frequencies are calculated for the whole fixed object. A next step is to make a distinction for different parts of an offshore installation. For example, it may be more relevant to know the contact frequency of a specific riser on a platform.

To further improve the risk assessment models such as SAMSON, a traffic flow model could be created that produces simulated "AIS-data" for a larger sea area. This model would be able to "predict" the traffic flows of the future and could be applied to the dynamic risk model to get an even better understanding of the risk posed to a fixed object at sea.

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