A Navigational Risk Assessment Method for Offshore Wind Farms

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Abstract: Offshore wind power is a clean energy that has been developing rapidly over the past decade in China. Compared with onshore wind power, it has several advantages including no occupancy of land space, abundance in wind resource and suitability of large-scale development. However, offshore wind farms (OWFs) inevitably endanger safety of navigation of ships. This paper provided a literature review of the state of the art on risk assessment of OWF, and proposed a novel mathematical method for navigational risk assessment (NRA), which has been applied in the assessment of an OWF.

Key Words: OWF; NRA; Safety of Navigation; AIS

0. Introduction

Currently, the GHG emission generated by human activities are still rising each year. The 13th Sustainable Development Goal for addressing climate change called for affordable and effective solutions from all countries to ensure the health and resilience of national economies. China has been taking strong measures to address climate change and is committed to peaking the CO2 emission as soon as possible by 2030 and accomplishing carbon neutral by 2060. Offshore wind energy is a renewable and clean energy source with zero CO2 emission. In comparison with offshore wind power, it has several advantages, inter alia, no occupancy of land space, abundance in wind resource and suitability of large-scale development. Since the development of the first commercial OWF, China’s offshore wind sector has been growing rapidly. However, the rapid development of offshore wind industry has made the navigation environment more complicated. For examples, inadequate distance to shipping routes, waterways and anchorages may present a risk of allision between ship and wind turbine, unsuitable establishment and maintenance of Aids to Navigation (AtoNs) may confuse the navigators and induce improper handling of ships, the electromagnetic radiation generated during the operating phase of OWF may affect the navigational equipment on board ships (LIANG, 2018).

1. Literature review

It's widely recognized that the navigational risk assessment should be duly carried out during the design, construction and operating phase of an OWF, providing valuable information for decision makers on OWF siting and minimum safety distance, etc. Regarding to the risk assessment of OWF, Mehdi et al. (2020) proposed a dynamic risk assessment model to address safety of navigation concerns around offshore renewable energy installations, it could be used by operational users such as VTS operators, pilots, shore-control centers and seafarers to make better and risk-informed decisions during the operation of vessels near OWFs in restricted, high-traffic-density areas. YU et al. (2020) developed a semi-qualitative risk model to assess the ship-wind turbine collision risks by incorporating Bayesian networks (BN) with evidential reasoning (ER) approaches. LI et al. (2013), established risk assessment criteria and risk assessment model during operating phase using fuzzy network analysis and support vector machine, providing reliable basis for risk management of OWF during operating phase. XIE, Z.Z. (2013), put forward OWF risk assessment criteria system including natural hazards, accidents, breakdown of facilities, management risks and market risks, and proposed the OWF risk assessment model using support vector machine. Similarly, JIANG et al. (2014), proposed the OWF risk assessment criteria system, including natural conditions, traffic conditions, AtoNs, turbine conditions, VTS, emergency response, etc., then a comprehensive assessment was conducted using fuzzy comprehensive evaluation method. Moulas et al. (2017), developed a nonlinear finite element analysis (NLFEA) approach to identify various collision scenarios and evaluate the damage to offshore wind foundations stricken by infield vessels.

2. Introduction of risk assessment models

There are plenty of risk assessment methods developed so far, all of which basically fall within two kinds: quantitative methods using “objective” data and qualitative methods using “subjective” expert judgement (Schröder-Hinrichs, 2020). Quantitative risk assessment methods include Event Tree Analysis (ETA), Fault Tree Analysis (FTA), Preliminary Hazard Analysis (PHA) and Risk Contribution Tree (RCT), etc. Qualitative risk assessment methods include Failure mode, effects and criticality analysis (FMEA/FMECA), Hazard and Operability Analysis (HAZOP), Fuzzy Comprehensive Evaluation (FCE) and Bayesian Networks (BN), etc.

Risk assessment models are replications of real-life systems and processes. Many scholars, over the years, have developed risk assessment models for many scenarios. Nonetheless it has been acknowledged that the NRA conducted by different organizations have received discrepant results for the same OWF. This discrepancy in calculations arises because different countries and organizations use different calculation models and procedures (Mehdi & Schröder-Hinrichs, 2016). Table 1 gives a comparison of the NRA processes in the seven countries (Mehdi et al., 2018). Currently, the China’s management provision on safety of navigation of water borne activities has no recommendation on which NRA models or tools could be used. Thus, the use of models or tools during NRA is diversified, the OWF developer may have to use a qualitative approach with experts judgement, but could the invited experts represent the interests of all relevant stakeholders? Or the developer may have to choose a quantitative model, but is the model transparent? The report of Ellis et al. (2008) implied that it was impossible to replicate the calculation results of certain models, as the equations and data values being used were not evident (as cited by Mehdi & Schröder-Hinrichs, 2016). In addition to inconsistent assessment results, the problem of using multiple models may also place additional burden on owners by having to follow different assessment procedures.

Table 1 Comparison of NRA process in the seven countries

<table>
<tr><th>No.</th><th>Question</th><th>UK</th><th>DE</th><th>DK</th><th>NL</th><th>SE</th><th>US</th><th>CN</th></tr>
<tr><td>1</td><td>Is a marine licence necessary for OWF approval in your country?</td><td colspan="7">Yes</td></tr>
<tr><td>2</td><td>Is a NRA necessary for OWF approval in your country?</td><td colspan="5">Yes</td><td>No, but generally included.</td><td>Yes</td></tr>
<tr><td>3</td><td>Who is responsible for conducting this NRA?</td><td colspan="3">OWF Developer</td><td>Maritime authority</td><td colspan="3">OWF Developer</td></tr>
<tr><td>4</td><td>Do you have any national guidelines on NRA?</td><td colspan="2">Yes</td><td>Internal only</td><td colspan="4">Yes</td></tr>
<tr><td>5</td><td>Do you require the use of any specific models, tools or methods when a NRA is conducted?</td><td>No. Recommend FSA; ANATEC's COLLRISK Model commonly used often by developers to compare base case vs. future case risk.</td><td>Yes. German Hazardous Incident Ordinance, the British Safety Case Regulations for offshore installations, IMO regulations for risk assessment to be followed. Models from DNV GL most commonly used by developers to compare base case vs. future case risk.</td><td>No. Recommend FSA; DNV MARCS model, and models from COWI and Rambøll most commonly used by developers to compare base case vs. future case risk.</td><td>No. Recommend FSA; MARIN's SAMSON model used most commonly to compare base case vs. future case risk.</td><td>.
No. Recommend IWRAP MKII model; SSPA model most commonly used by developers to compare base case vs.future case risk.</td><td>No. Recommend 'What-if' analysis amongst other tools.</td><td>No. Recommend assessment approaches as follows: comprehensive analysis of data; mathematical model; simulation; sea trials; expert consultation.</td></tr>
<tr><td>6</td><td>Are there any specific factors that must be considered in a NRA -e.g. - specific ship type, size,speed, weather conditions, etc.?</td><td colspan="7">Ship traffic, speeds and types through AIS data, dynamic (wind, wave, tides, currents, etc.) and static (bathymetry, hydrographic features, layout of channels, etc.) environmental conditions, OWF location and layout.</td></tr>
<tr><td>7</td><td>Are there any guidelines for approving a wind farm with regards to navigation safety?</td><td>No. Case by case basis.</td><td>Yes. turbine must be collision friendly, and not rupture hull of a predetermined vessel drifting into it at 2m/s.</td><td colspan="5">No. Case by case basis.
*In DK, turbine must be collision friendly.</td></tr>
</table>

Notes: UK = United Kingdom, DE = Germany, DK = Denmark, NL = The Netherlands, SE = Sweden, US = United States of America, CN = China.

Source: Adapted from "Improving the coexistence of offshore wind farms and shipping: an international comparison of navigational risk assessment processes", by Mehdi et al., 2018, p.407.

3. The mathematical method for navigational risk assessment

All vessels of displacement will leave trails in the water by fueling the waves as they sail. Simultaneously, the trails or rather trajectories could be also logged electronically in the AIS-based systems, then displayed graphically on ECDIS. The historical tracks of all ships passing through a waterway will be accumulated to form a “Trajectory Plane”, the distance between “Trajectory Plane” boundary and waterway boundary represents the closest distance between passing ships and waterway boundary. In order to analyze navigational risks of ships more objectively, a mathematical method has been proposed to calculate the Distance of Closest Approach (DCA) and Average Distance of Approach (ADA) between passing ships and OWF based on AIS data of the ships.

Suppose the horizontal line segment MN is a cross section that crosses a shipping route, and a ship is projected vertically on the plane as shown in Figure 1. Point O is located at the half width of the bridge of the ship, representing the GNSS coordinate position of the ship. The heading course of the ship is C when she crosses the MN, and the breadth of the ship is B. If the positioning error, leeway and drift are ignored, the distance between M and P (the intersection point of MN and port side of the ship’s projection), and N and S (the intersection point of MN and starboard side of the ship’s projection) can be expressed as equations (1) and (2):

$$\mathrm{MP} = |MO| - \frac{B}{2\sin(90-C)} = |MO| - \frac{B}{2\cos C} \quad \text{.........\# (1)}$$

$$\mathrm{NS} = |NO| - \frac{B}{2\sin(90-C)} = |NO| - \frac{B}{2\cos C} \quad \text{.........\# (2)}$$

Note: The unit of B is meter, the unit of C is degree.

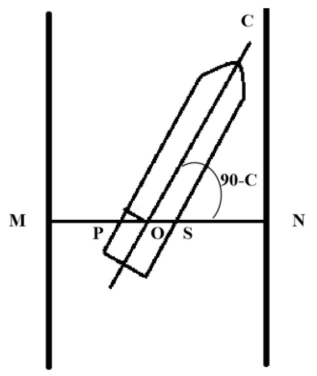

Figure 1 The cross section MN and vertical projection of a ship

If the cross section is not horizontal, and there is an angle β between the cross section and latitude as shown in Figure 2. Figure 2 only shows that the ship's heading course is between 0° and 90°. In fact, no matter which quadrant the ship's heading course is located in, the discussions can be divided into three scenarios.

A. The latitude of N is higher than that of M. The distance between M and P, and N and S can be expressed as equations (3) and (4):

$$\mathrm{MP} = |MO| - |\frac{B}{2\cos(\beta+C)}| \quad \text{.........\# (3)}$$

$$\mathrm{NS} = |NO| - |\frac{B}{2\cos(\beta+C)}| \quad \text{.........\# (4)}$$

B. The latitude of N is lower than that of M, and C> β. The distance between M and P, and N and S can be expressed as equations (5) and (6):

$$\mathrm{MP} = |MO| - |\frac{B}{2\cos(C-\beta)}| \quad \text{.........\# (5)}$$

$$\mathrm{NS} = |NO| - |\frac{B}{2\cos(C-\beta)}| \quad \text{.........\# (6)}$$

C. The latitude of N is lower than that of M, and C< β. The distance between M and P, and N and S can be expressed as equations (7) and (8):

$$\mathrm{MP} = |MO| - \left|\frac{B}{2\cos(\beta - C)}\right| \quad \text{.........\# (7)}$$

$$\mathrm{NS} = |NO| - \left|\frac{B}{2\cos(\beta - C)}\right| \quad \text{.........\# (8)}$$

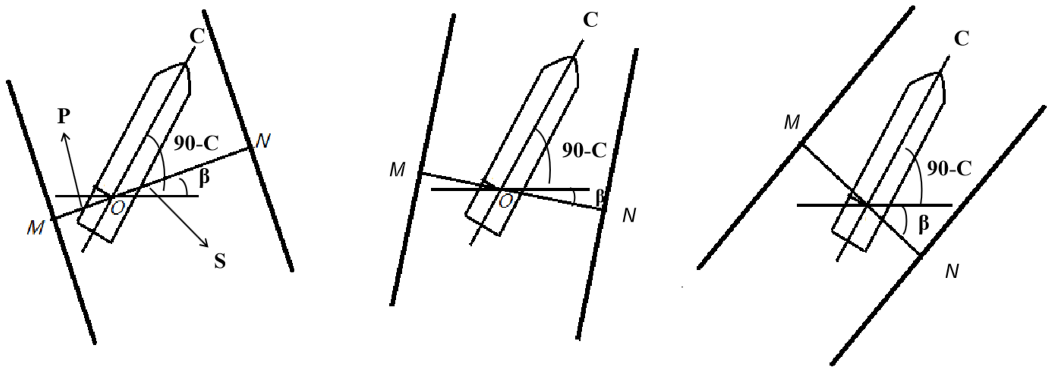

Figure 2 Positional relation between heading course and MN

4. Application of the method

4.1 Selection of an OWF

Binhai North OWF is situated in the offshore sea area between Zhongshan Estuary and Binhai Port, which generally contains two blocks of wind farms (H1 & H2) established separately in around 2017 and 2018. The site location of Binhai North OWF is delineated in Figure 3. The Binhai North H1 OWF consists of twenty-five rectangularly distributed wind turbines, with the offshore distance of 7.5 km and the depth of water ranging mostly from 7 to 13 metres. The Binhai North H2 OWF consists of a hundred polygonally distributed wind turbines, with the offshore distance of 22 km and the depth of water ranging from 15 to 18 metres.

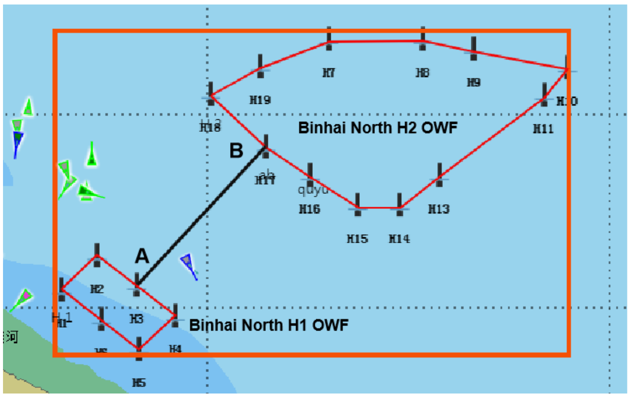

Figure 3　　The site location of Binhai North OWF

According to "The planning of Jiangsu coastal shipping routes" developed by Jiangsu Maritime Safety Administration in 2012, there are generally four shipping routes adjacent to Binhai North OWF as delineated in Figure 4. First, the northbound deep-water route approaching Guanhe kou, with the closest distance of 3.1 NM to Binhai North H2 OWF. Second, the northbound shallow-water route approaching Guanhe kou, with the closest distance of 3.1 NM to Binhai North H2 OWF. Third, the two-way route between Guanhe kou and Binhai, with the closest distance of 1.8 NM to Binhai North H1 OWF, and of 3.8 NM to Binhai North H2 OWF. Fourth, the northbound shallow-water route approaching Lian Yungang, with the closest distance of 3.7 NM to Binhai North H2 OWF.

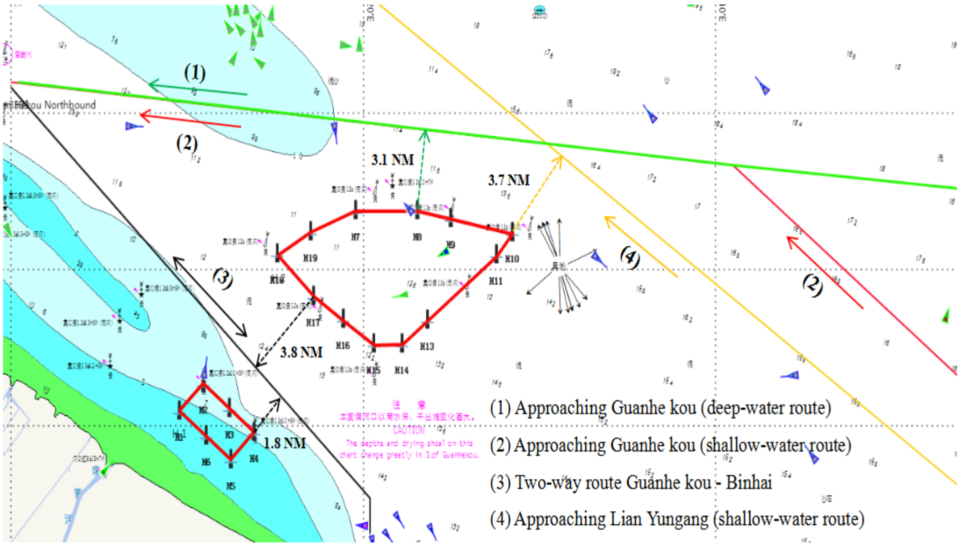

Figure 4　The shipping routes adjacent to Binhai OWF

4.2　Navigational risk assessment

Two points A（34°24′44″N / 120°12′25″E）and B（34°29′N / 120°17′12″E） on the periphery of Binhai North OWF are selected. Connect point A and B as the cross section that passes through the two-way route between Guanhe kou and Binhai, see figure 3. The Equation (3) and (4) can be used to calculate the DCA between ships passing through the cross section and Binhai North OWF, and the ADA can be obtained by arithmetical average of the approach distances of all passing ships.

First of all, extract AIS data of all ships passing through across section AB from Lian Yungang Aids to Navigation Department from September 2020 to May 2021. Then, parse the heading courses, coordinates, beams of ships and other information. Finally, calculate the DCA and ADA between passing ships and Binhai North OWF, see table 2. As can be seen from the computed results, some ships passed the OWF with a very small distance of 0.27 NM approximately, which is certainly not a safe passing distance. Based on the achievements of the navigational risk assessment, with a view to enhancing safety of navigation, the maritime authorities should establish further risk mitigation measures.

Table 2　Computed results

	DCA (m)	ADA (m)
The distance to Point A of Binhai North H1 OWF	506.5	2482.3
The distance to Point B of Binhai North H2 OWF	555.4	9969.5

5. Conclusions

Plenty of NRA models have been developed and widely used in the risk management of OWFs so far, nevertheless the diversified use of NRA models needs to addressed in that different models used on the same area may obtain diverse outcomes. It can be said with certain conviction that there is no one-size-fits-all model. In an ideal framework, it is therefore prudent to select a variety of models that can complement each other and provide a very comprehensive overview of the situation. This paper proposed a simple mathematical method for navigational risk assessment and applied it to Binhai North OWF, providing a quantitative analysis tool for navigational risk assessment of OWF based on objective AIS data. The mathematical method is simple and easy to understand, but the calculation of the DCA and ADA were manually conducted. Therefore, the calculation workload is heavy and inefficiency for the waters with high volume of traffic. In order to improve the efficiency, it is necessary to develop a computer-based automatic calculation method in the future.

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