MOSWOZ simulator study

Final report

INTERGO
International Centre for Safety
Ergonomics & Human Factors

SIMWAVE
MARITIME CENTRES OF EXCELLENCE

Colophon

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Table of contents

1. Introduction

1.1 Background

The North Sea, one of the busiest maritime areas in the world, is not only used for shipping but also for various other activities, including energy production. With the ambition to significantly increase offshore wind energy production in the coming decades to meet climate goals, important questions arise regarding maritime safety. To ensure continued safety, Rijkswaterstaat (RWS) investigates the impact of offshore wind farms (OWFs) and has initiated the Offshore Wind Energy Shipping Safety Monitoring and Research Programme (MOSWOZ). In the complex and sometimes stressful environment of the North Sea, human factors aspects are crucial in preventing collisions. Ship crews can regularly encounter critical situations that require quick decision-making. Understanding the impact of stress, fatigue and increased pressure on decision-making is essential.

For the future situation RWS will take measures to mitigate the possible safety effects of the wind farms:

- **Vessel Traffic Monitoring (VTMon)** | VTMon operators will monitor the OWF areas, support shipping crews and take measures when needed;
- **Emergency Response Towing Vessel (ERTV)** | When ships are in need the ERTV can help the ship and tow it to a safer area;
- **Deep sea pilot** | A deep sea pilot navigates vessels through complex or challenging waters, like the narrow and crowded water ways around the wind farms.

In this context, Intergo and Simwave have conducted a simulator study on human factors aspects.

1.2 Research question

The main research questions of the study were:

1. **What is the effect of the wind farms and increasing traffic density on the North Sea on the sailing behaviour of the ship crews?**
2. **How effective are the mitigating measures?**

The main research questions were translated to 56 sub-questions that were answered individually during the simulation runs.

1.3 Scope

This simulation study was executed according to predefined scenarios and research questions created by RWS and external parties. This study is to provide answers to the research questions which allows RWS to determine whether additional (safety)measures are needed, and if so, which ones.

1.4 Reading guide

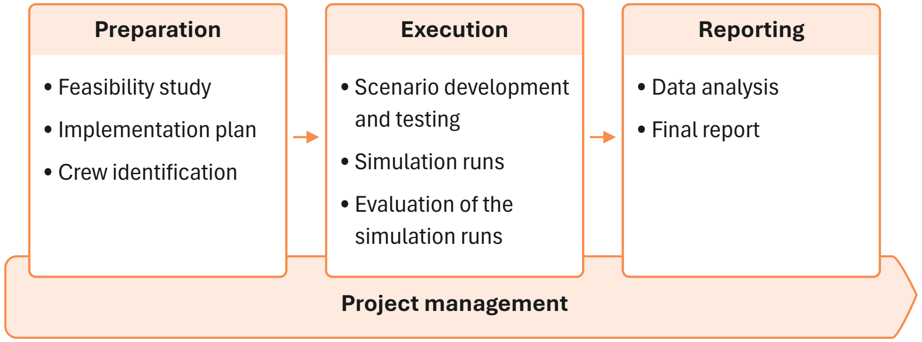
This document provides a concise overview of the approach, results, conclusions, and limitations (discussion) of the MOSWOZ simulator study. For a more comprehensive explanation of these topics, please read the referenced documents.

Chapter 2 outlines the research approach, followed by an overview of the simulation setup in Chapter 3. Chapter 4 addresses results. Chapter 5 provides a discussion section with the limitations of the study, offering a nuanced perspective on its scope. Finally, Chapter 6 concludes with the key findings and recommendations.

2. Approach

Qualitative research was conducted to study participants' behaviour during eight maritime scenarios on the North Sea, set in the year 2030. The scenarios were defined by RWS prior to the study, along with research questions tailored to each scenario. This chapter provides a concise overview of the research phases, the scenarios, the participants, the measurement instruments, and the simulators used.

The research project contained three phases: preparation, execution and reporting.



2.1 Preparation

Feasibility study

In the first step of the preparation phase a feasibility study was performed. The aim of the study was to assess the feasibility of the simulation runs and the associated human factors monitoring. Specifically, the following issues were addressed:

- Refinement of the research questions.
- Scenario events.
- Methodological feasibility.
- Technical feasibility.
- Manning.

The feasibility study identified a few minor challenges, for which mitigating measures were proposed. These measures were approved by RWS, leading to a positive feasibility conclusion.

A brief overview of the scenarios is provided later in this section, while a detailed account of the study can be found in the report Feasibility Assessment [1].

Implementation plan

The implementation plan was developed following the feasibility study. It outlined the research method and measurement plan used during the simulation study, addressing the following key topics:

- Relationship between scenario events and research questions: How specific events within the scenarios aligned with the research questions.
- Crew members and involved personnel: Identification of personnel and their roles.
- Assessment instruments (measurements and tools): The tools and methods used for data collection, which are further detailed later in this chapter.
- Procedure: Description of activities conducted during the scenario runs.
- Data analysis plan: Strategy for collecting and analysing the required data.

To ensure quality, the implementation plan was reviewed by an independent professor from the University of Twente (UT), Faculty of Behavioural, Management and Social Sciences (BMS). After incorporating feedback from UT and RWS, the implementation plan was approved by RWS.

A comprehensive description of the study is available in the report Implementation Plan [2].

Crew identification

The third step of the preparation phase involved identifying and formalising the required crew members for the scenario runs. Once approved by RWS, the crew members were hired and scheduled. An overview of the participating crew members and their roles is provided in Table 1: Participants per Scenario on page 6.

2.2 Execution

Scenario development and testing

The first part of the execution phase was the development and testing of the scenarios. The simulations were tested on accuracy, performance and stability during desktop testing and afterwards in the 360º simulators. Subsequent to testing, several issues were identified and resolved, after which approval was granted by RWS.

A detailed description of the testing is found in the report Simulation development and testing [3]. The used simulators are described in section 'Simulators' on page 7.

Simulation runs

After testing, the simulation runs were conducted over ten days within a three-week period from October 25 2024 to November 10 2024. Some scenarios were scheduled during the day, while others took place during the evening. Each scenario began with an introduction to its context and a familiarisation session with the simulators. Following this, the crew received instructions and, if necessary, prepared for the voyage. The actual simulation run then commenced.

During the runs, observers monitored crew behaviour, logged events and actions. Each scenario concluded with a reflection report (questionnaire) and a plenary debriefing session. Simulation days typically lasted between six and nine hours.

Evaluation of the simulation runs

When finished the simulation runs were evaluated on the following issues:

- General evaluation: the evaluation of the procedure of the simulation days and the simulation equipment used during the simulation runs.
- Crew evaluation: evaluation of the role performance, issues that occurred and mitigating measures.
- Scenario evaluation: evaluation of the events and noteworthy events that occurred during the simulation run.

Although not every event unfolded as planned, interventions by the research team made it possible to create or approximate the desired situations. In one scenario, the captain's role did not align with expectations. However, the results still revealed valuable observations that were relevant to the study.

A detailed description of the evaluation can be found in the report Structured Evaluation Simulations [4].

2.3 Reporting

Data analysis

The reporting phase started with a data analysis. For each scenario, the results were analysed and used to address the corresponding research questions. The findings related to the main research questions are presented in the next chapter of this report, while detailed answers to the specific research questions are provided in the Data Analysis Report [5].

Final report

The second step of the reporting phase involved compiling the final report, which is this document.

3. Setup simulation runs

3.1 Scenarios

Below, the simulated scenarios are briefly described. Figure 1 and Figure 2 illustrate the visualised simulated environments in which the scenarios were conducted. These visuals highlight the specific areas in which the predefined events unfolded. It is worth noting that the overall simulated areas in the simulator were larger than the zones where the events took place.

Scenario 1 | Basic scenario

A merchant vessel sailed through the North Sea and experienced dense traffic in vicinity of the OWFs, reflecting the conditions of 2030. The scenario was conducted twice, once with an experienced crew and once with a less experienced crew.

Scenario 2 | Dragging Anchor

A merchant vessel unexpectedly had to anchor at a regular anchorage. When the weather began to deteriorate, the vessel's anchor started dragging. The vessel was unable to restart its engines and drifted towards the OWF. The VTMon and Emergency Response Towing Vessel (ERTV) were both included in the scenario.

Scenario 3 | Collision – Not Under Command (NUC)

A merchant vessel had a collision with a container ship, north of OWF Hollandse Kust West (HKW) lot VI. The engine room took on water, causing a blackout and a 10° list. The vessel drifted towards OWF HKW. The VTMon and ERTV were both included in this scenario.

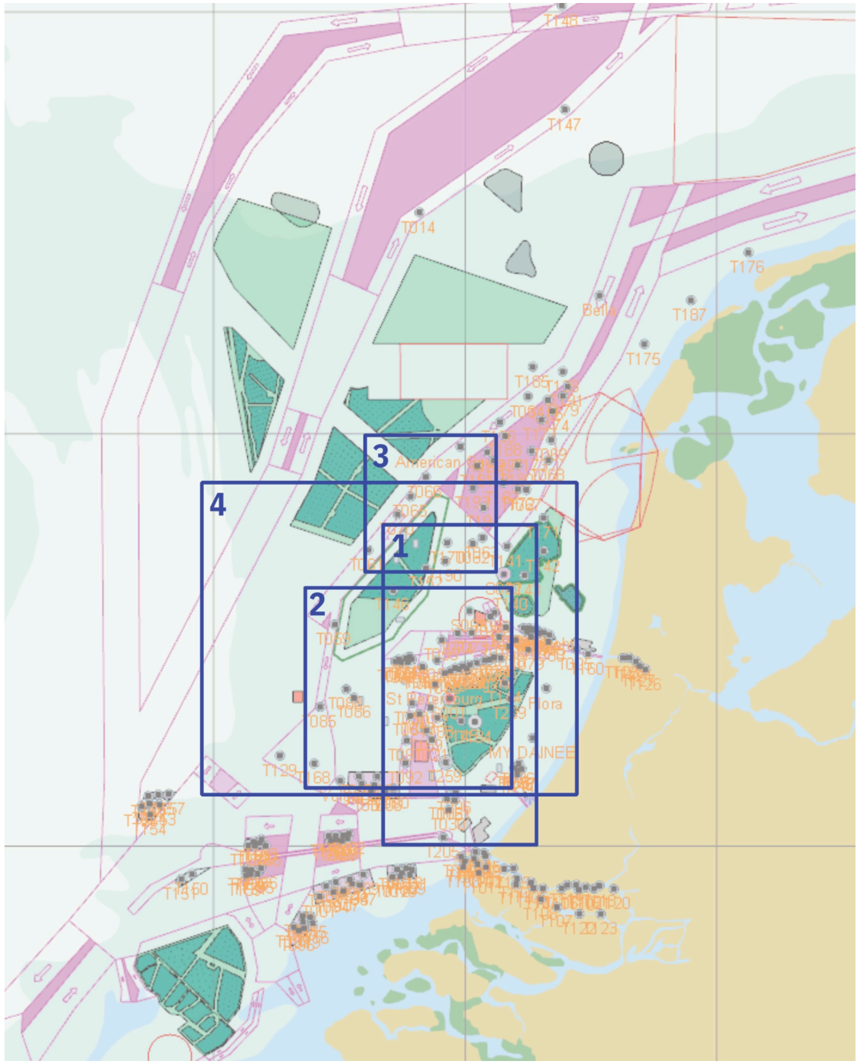


Figure 1. An overview of the simulated areas for scenario 1 to 4. The blue outlines indicate the location in which the predefined events unfolded.

Scenario 4 | VTMon summer

VTMon operators monitored the OWF area in the North Sea. The scenario took place during summertime with recreational yachts and good weather. At various times, events were put into the scenario.

Scenario 5 | VTMon Autumn

VTMon operator monitored the OWF area in the North Sea. The scenario took place during late Autumn with severe weather and without recreational yachts. At various times, events were put into the scenario.

Scenario 6 | Loss of unmanned tow

A tug was towing an unmanned car carrier. The tugboat lost the tow due to adverse weather, and the tow drifted towards the nearby OWF. The ERTV and VTMon were included in the scenario.

Scenario 7 | Using passage or detour

Five experienced and five unexperienced sailing yacht skippers made a voyage planning from Harwich to IJmuiden and Hull to IJmuiden. Afterwards they sailed multiple times through the passageway for small vessels of OWF HKZ, under different conditions.

Scenario 8 | Sensor failure

A merchant vessel sailed through the North Sea and experienced dense traffic in vicinity of the OWFs, reflecting the conditions of 2030. During the voyage the vessel experienced GPS failure.

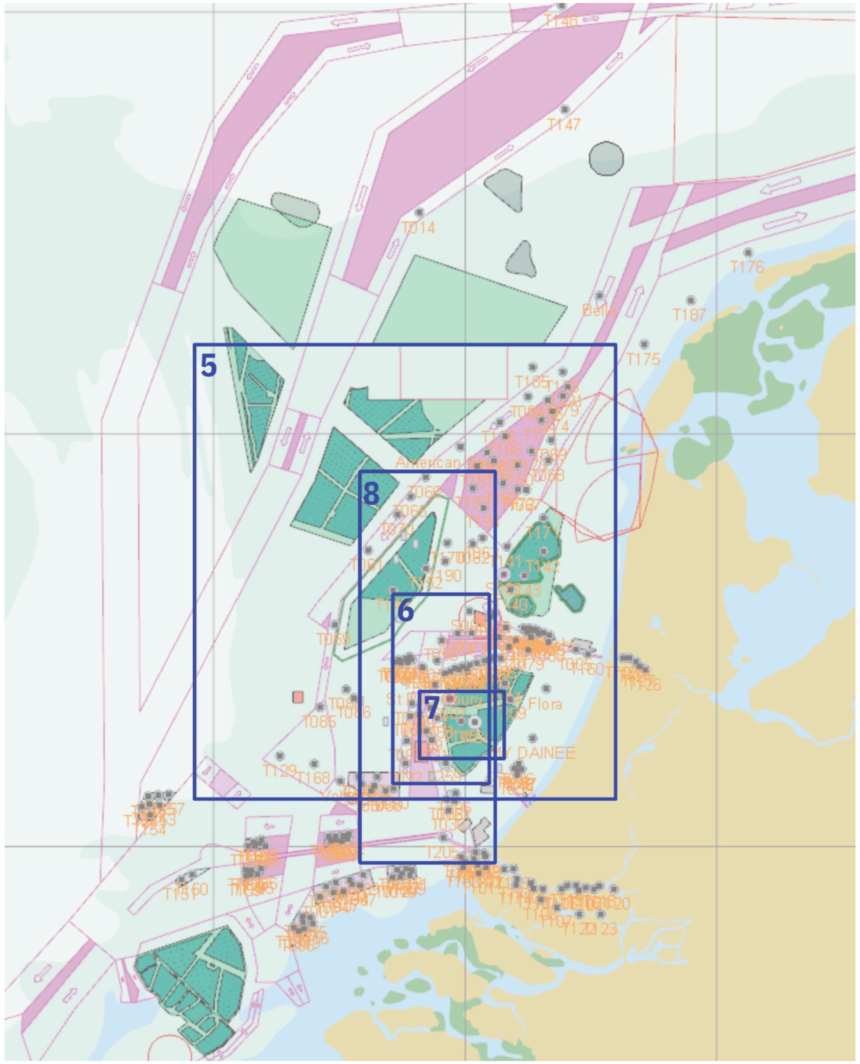


Figure 2. An overview of the simulated areas for scenario 5 to 8. The blue outlines indicate the location in which the predefined events unfolded.

3.2 Participants

Participants of the simulation runs included two merchant vessel crews (captain, 2nd-and 3rd officer and lookout/helmsman), multiple ERTV crews (captain and 2nd officer), multiple VTS operators with North Sea experience acting out the VTMon role, a tugboat crew (Captain and 2nd officer), a deep sea pilot, a salvage expert, six experienced sailing yacht skippers (experience with sailing the North Sea in the vicinity of OWFs) and five inexperienced sailing yacht skippers (see Table 1).

Table 1. Participants per scenario

Participants	*Scenarios*
Crew 1: captain, 2nd-and 3rd officer and lookout/helmsman	1A
Crew 2: captain, 2nd-and 3rd officer and lookout/helmsman	1B,2,3,6,8
ERTV crews	2,3,4,5,6
Sailing yacht skippers	7
VTMon operators	2,3,4,5,6
Deep sea pilot	2,3,8
Salvage expert	6

3.3 Measurement instruments

During the simulation runs, triangulation of assessment instruments was applied by utilising multiple tools for data collection. The following measuring instruments were employed:

- **Observations:** Observations focused on the sequence of events and decision-making processes, incorporating the ‘thinking out loud’ procedure that participants were encouraged to use. Observations were conducted by at least two human factors experts. Additionally, domain experts (e.g., a salvage expert, deep sea pilot, and tugboat captain) were involved during specific scenarios to provide valuable insights.
- **TAS and RSME:** These instruments were used to measure the experienced threat (TAS) and mental effort (RSME) throughout the scenarios.
- **Reflection report:** Individual questionnaires addressing the topics described above were tailored to each role and completed at the end of each scenario.
- **Debriefing:** A plenary debriefing was conducted with all participants, using a semi-structured list of scenario-specific questions to facilitate discussion and gain a deeper understanding of the observations.
- **Eyetracking:** Eyetracking technology was utilised to measure the situational awareness of the VTMon.
- **Simulator data:** Data such as TCPA and CPA of other vessels and wind turbines were analysed to determine detection times and quantify dangerous situations, such as near miss encounters.

3.4 Simulators

Four different simulators were utilised during the scenarios, with the specific simulator(s) selected based on the scenario requirements. Up to three simulators operated simultaneously within the same environment and scenario. An overview of the simulators is provided below:

- **360-Degree Full Mission Bridge:** This simulator was used for the merchant vessel and towing vessel across five different scenarios (Figure 3).
- **360-Degree Offshore Full Mission Bridge:** This simulator was employed for the Emergency Response Towing Vessel (ERTV) in five scenarios (Figure 4).
- **VTMon Station:** A modified part-task bridge simulator equipped with ECDIS, radar, and an improvised overview screen that displayed a list of ships with their corresponding (T)CPA values used in five scenarios (Figure 5).
- **Part-Task Bridge Simulator:** Used by sailing yacht skippers, this simulator featured an outside view, ECDIS, navigational equipment (including steering), GPS, VHF, autopilot, and meteorological instruments and was used in one scenario (Figure 6).

Figure 3. The 360 FMB bridge used for the merchant vessel and tugboat.

Figure 4. The 360 degrees offshore FMB used for the ERTV.

Figure 5. The VTMon station.

Figure 6. The part-task bridge simulator used by the sailing yacht skippers.

4. Results

Results of the study are summarised and presented per main research question. The specific research questions drafted per scenario are answered in the Data analysis report [5].

4.1 Behaviour of ship crews

The results of this section relate to the first research question: "*What is the effect of the wind farms and increasing traffic density on the North Sea on the sailing behaviour of the ship crews?*". The results are categorised for the crew of 'merchant vessels' and 'sailing yacht skippers'.

Merchant vessels

In the basic scenario, Scenario 1, the crews mentioned during the debriefing that they did not experience sailing in between the OWFs as extremely demanding. Even though there was a difference between the mental effort between experienced and less experienced crew, the RSME scores were never extremely high (see Figure 7). The peaks in mental effort refer to specific events: the chief officer taking a short watch alone while other vessels are around and a black out of the vessel.

In more demanding scenarios like scenario 3 (collision) the experienced mental effort was higher (see Figure 8).

During the debriefings crew members explained that they perceived the OWFs as static no-go areas. During (emergency) situations OWFs were avoided and dropping anchor was seen as a last resort to avoid drifting into an OWF. However, on one occasion the crew decided to move closer to the OWF to avoid collision with a vessel that had slowed down ahead of them. A distance of 1.5 NM from an OWF was not considered dangerous or uncomfortable.

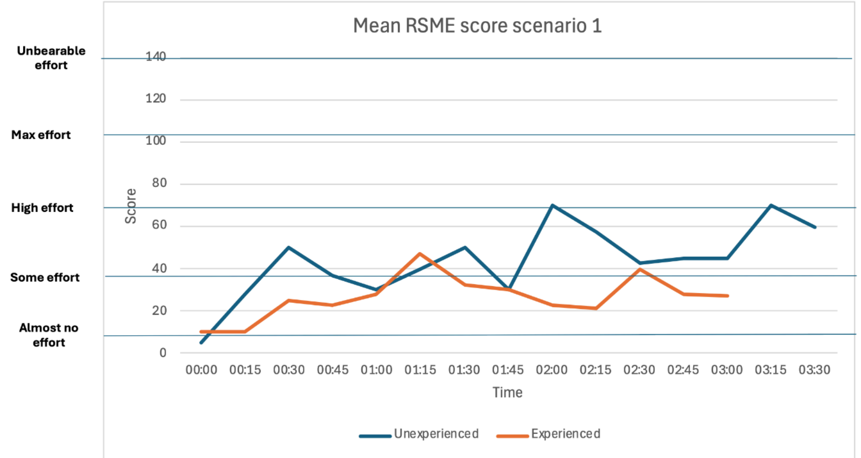


Figure 7. Mean RSME scores crew scenario 1.

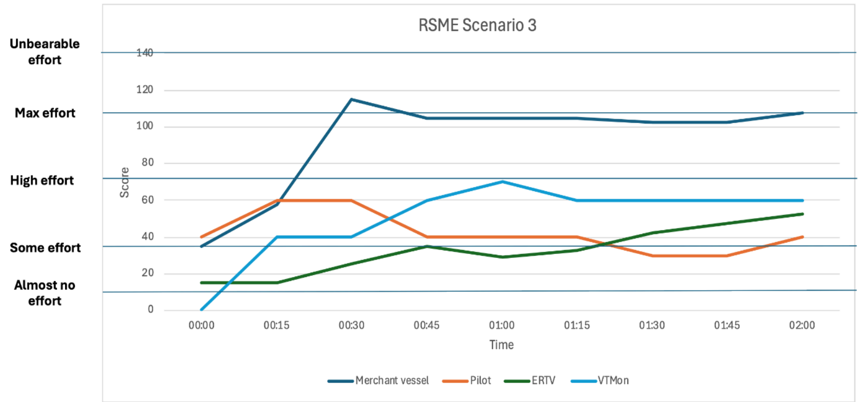


Figure 8. RSME scores in scenario 3 (collision).

TCPA' and CPA's[1] of noticing other vessels showed that there was enough time for the crew to react properly. In general, TCPA's and CPA's were >0.5NM and >10min of detecting a vessel.

One crew showed that during GPS failures it was able to keep situational awareness and take appropriate action when needed. Overall, the observations and simulator data showed that the crew was situationally aware of their surroundings and the vessels that required attention and/or decision making.

Exceptions in which the crews showed difficulties with situational awareness were sailing yachts without AIS. In some scenarios the crew did not, or very late, detect the sailing yachts causing near miss encounters. This was caused by (1) a single officer doing watch-duty because the lookout was occupied with hand steering the vessel and (2) a confusion of lights of other vessels that was in the visual line of sight of the sailing yacht.

During the debriefings, the crew members mentioned that they experienced an increase in traffic density to be more challenging than the direct effect of the OWFs.

During voyage preparation the crew barely made any considerations on the OWFs. On one occasion a crew mentioned workboats coming and going from OWFs as a point of attention.

When dropping anchor crews checked the vicinity for pipelines and cables. One crew decided to not drop anchor because of nearby pipelines and cables. In case of immediate threat to the crew's safety, a captain mentioned to drop the anchor near cables and pipelines as a last resort. The crew seriously questioned the effectivity of dropping anchor in emergency situations when the vessel's speed is 3-4 knots or more.

When facing a NUC situation (scenario 3), a Towing and Assistance Team (TAT) is considered as a support option.

[1] TCPA (Time to Closest Point of Approach) and CPA (Closest Point of Approach) are maritime navigation metrics used to assess collision risks, indicating the time and minimum distance between vessels if they maintain their current courses and speeds.

Communication between the crew and the VTMon and ERTV was as effective, it was prompt, clear, and concise.

Sailing yacht skippers

Figure 9 shows the planned sailing yachts skippers' routes from IJmuiden to Harwich and IJmuiden to Hull. Voyage planning of the skippers showed that some skippers preferred to sail through the transit passageway for small vessels of HKZ, while others preferred to sail North of HKZ. It is a balance of keeping away from large merchant vessels, thus sailing the passageway for small vessels. Or having more space to sail (with adverse weather conditions for example), thus choosing to sail the open waters. When planning a route from IJmuiden to Hull experienced skippers decided to go north of HKW, while the majority of inexperienced skippers planned to pass HKW on the southern end. Additionally, some skippers choose to sail around anchorages, while others plan their route through the anchorage. One sailor planned his route through HKN, which is not allowed.

When asked to plan a route starting southwest of the transit passageway for small vessels of HKZ to IJmuiden all skippers (except one inexperienced skipper) decided to use the transit passageway for small vessels.

During observation and the debriefing skippers mentioned that they wanted to keep away from large commercial vessels as much as possible. This was considered in their voyage planning. Therefore, the transit passageway for small vessels of OWF HKZ was perceived as a safer way to sail because there is little traffic and no large merchant vessels. However, under unfavourable weather conditions (wind direction, wind speed, current and waves) the skippers may consider avoiding the passageway for small vessels as it is seen as relatively small.

During the debriefing skippers mentioned that under poor visibility conditions (fog or nighttime) other vessels were occasionally missed or recognised late. In general, but especially with these conditions, skippers tend to stay as much to the starboard side of the fairway as possible to avoid dangers.

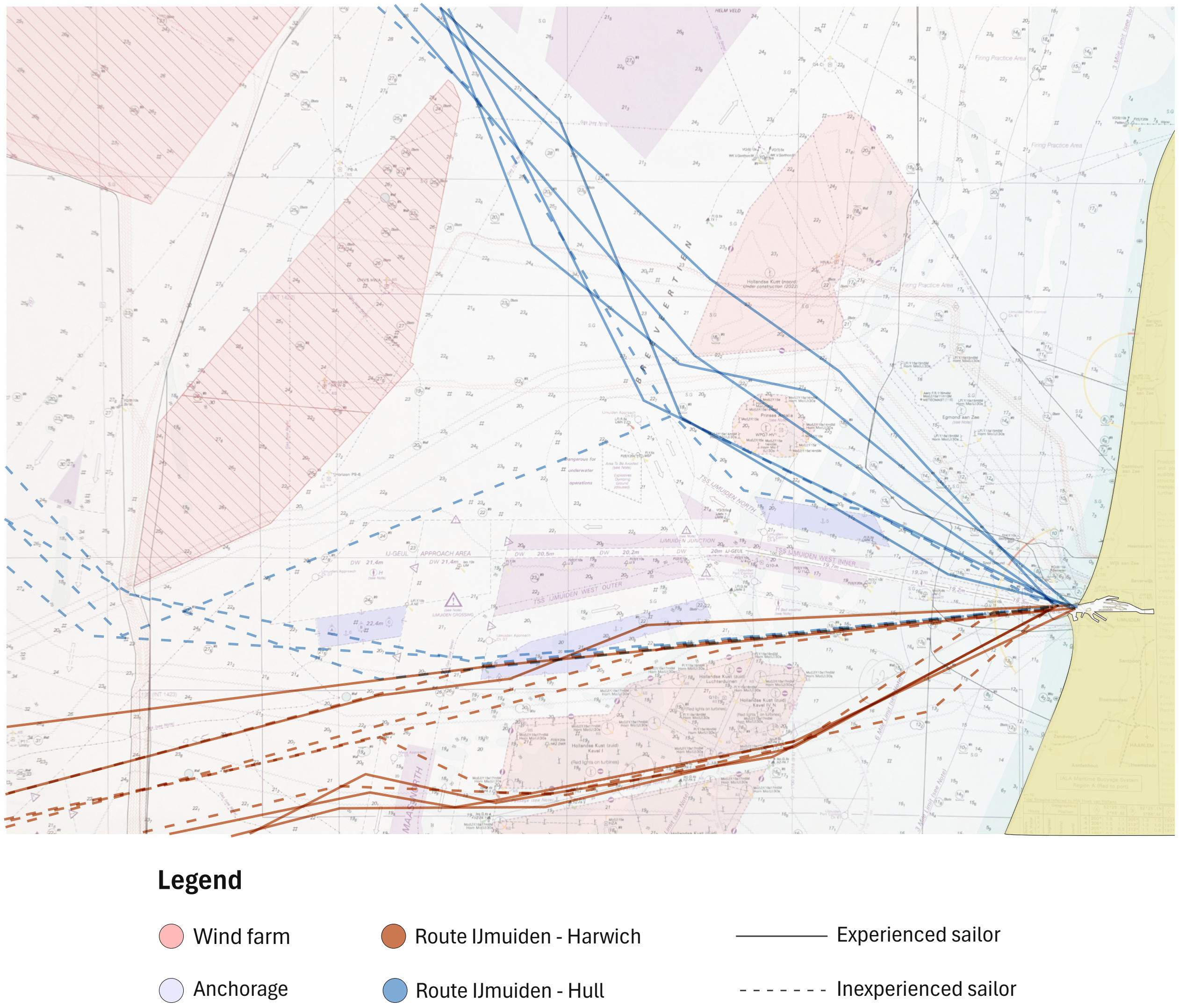


Figure 9. Visual summary of the routes planned by experienced and inexperienced sailing yacht skippers.

Wind direction was considered a more important factor on deciding to set sail than wind force. Sailors noted to set sail with windspeeds of 20 to 30 knots if the wind direction was favourable.

Sailors mentioned that it was difficult to distinguish different lights in the dark (ship, buoy, wind turbine, coastal lights).

Another finding of these scenarios was that the rules and regulations for entering the transit passage for small vessels of OWF HKZ were not very clear to the recreational sailors. Especially the legal limitations of vessels that enter into the corridors were unclear. There are different limitations for the corridor in Borssele, where vessels with a LOA over 45 meters are not allowed to enter, and the transit passage for small vessels in HKZ, where vessels with a LOA over 46 meters are not allowed to enter. In addition, the wind farms Egmond aan Zee and Prinses Amalia also have differing restrictions from Borssele and HKZ. Both wind farms do not have any transit passages. Vessels are allowed to enter these wind farms if they are under 24 meters LOA and if they abide by the rules of conduct for entering the wind farms [6].

Mental effort was not experienced as extremely high by the sailing yacht skippers. Skippers mentioned that higher scores at the start of the scenario were caused by the difficulty of using the autopilot. Later in the scenario the skippers learned how to use it.

4.2 Mitigating measures

The results of this section relate to the second research question: "*How effective are the mitigating measures?*". The results are categorised for the 'Vessel Traffic Monitoring (VTMon)', the 'Emergency Response Towing Vessel', and the 'Deep sea pilot'.

Vessel Traffic Monitoring (VTMon)

During the specific VTMon scenarios (4 and 5) the RSME did not show extreme scores. There were a few peaks scores of 70, which is still manageable as long as they do not sustain. Most anomalous situations were recognised in a timely manner. In the other scenarios (2, 3 and 8) scores were higher, around 60 and 70 and more enduring (see Figure 8). This was a result of the high demand situations during these scenarios.

This was in line with the finding that during incidents the VTMon operators were not fully capable to monitor the whole operational area and occasionally missed situations that required attention. In one scenario the VTMon failed to recognise a 142 meter vessel entering the OWF, because all attention was focused on other events (see Figure 10).

During the debriefing the operators mentioned that they missed a Duty Officer (DO) for assistance as an extra pair of eyes to monitor the operational area.

The scenarios showed prompt, clear, and concise communication between VTMon operators and other parties. The VTMon operators communicated with ships that were in need and deployed the ERTV directly. Besides that, they warned vessels in the surroundings and informed the OWF operator to stop wind turbines and evacuate personnel. Their experience as VTS operator seemed to be transferrable to the role of VTMon operator. However, The VTMon operators felt hindered in fulfilling their role due to a lack of proper VTMon equipment and tooling as they are used to during their work as VTS operator.

Although the VTS skills seemed transferrable to the VTMon function, the roles are not the same. At times this caused confusion for the operators. They missed a clear description (and training) of tasks, authorities and responsibilities.

The applied shifts of 1.5 hours were estimated as appropriate.

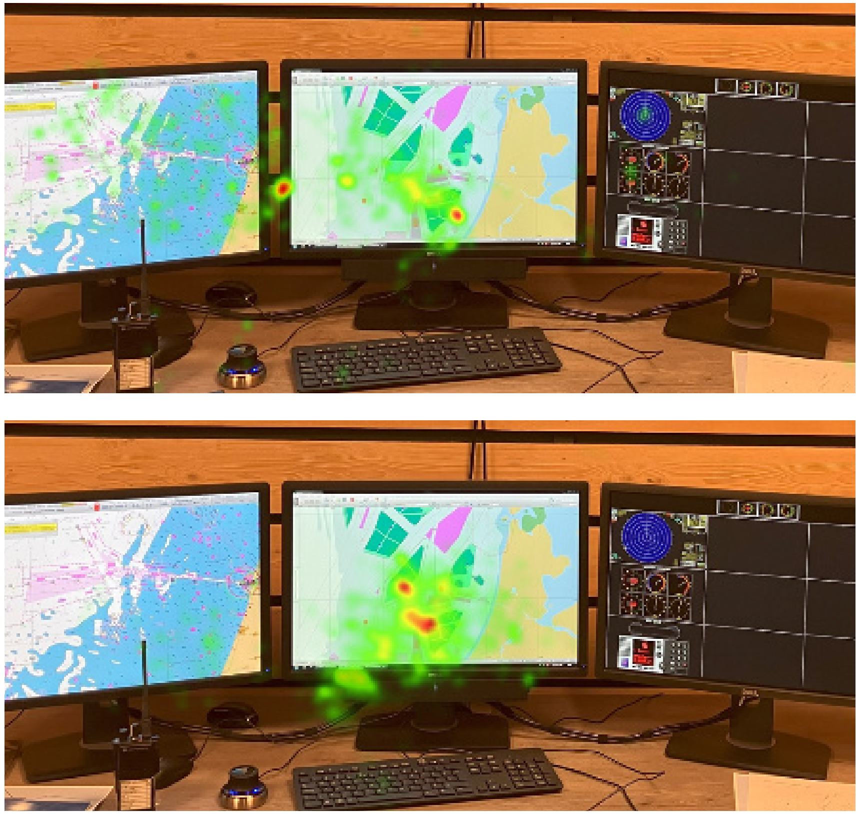


Figure 10. The eye tracking images show that the visual attention of the VTMon operator was fixed in specific events (red dots) and missed the ship sailing into the OWF (black circle).

Emergency Response Towing Vessel

In three high-demand scenarios (2, 3, and 6), the ERTV arrived just in time to assist the ship in distress. The deployment of the ERTV proved effective. However, in one scenario, the objective was to allow a merchant vessel to drift into the OWF, which required inducing an engine problem on the ERTV to ensure this outcome.

The timing of the ERTV's arrival posed challenges in certain cases. Strong winds and poor visibility occasionally prevented the ERTV from navigating through or entering an OWF, thereby increasing response times.

When establishing a towing connection, the ERTV crew took weather conditions and the towing options provided by the merchant vessel into account. During debriefings, crew members expressed a preference to avoid operating in close proximity to both a wind turbine and the merchant vessel to reduce the risk of being trapped between the two.

The options for reestablishing a towing connection or regaining control over the vessel include:

1. Catching the emergency wire of the tow.
2. Pushing the tow.

The latter option is never applied in practice due to the high risk of causing damage to the ERTV.

The ERTV crew did not find their role to be highly mentally demanding overall. The highest RSME scores were recorded at the end of Scenario 6, when they encountered engine problems during a towing operation (see Figure 12).

The results suggest that the ERTV crew's confidence likely stemmed from their prior experience with the coast guard, which was reflected in their proactive approach. The crew consistently monitored the situation using the ECDIS and VHF communication and occasionally preemptively deployed the ERTV before incidents occurred.

Deep sea pilot

Scenario 3 (collision) showed that the deep sea pilot, familiar with the North Sea area and emergency procedures, provided significant added value. The deep sea pilot had specific added value to the communication within the crew and with other parties. The added value was shown by the fact that the pilot new how to manoeuvre the ship effectively, even though the scenario was set up to evoke a collision. The simulator operator had to insert an extra ship to make the collision finally happen. Figure 8 also shows the relatively low experienced mental effort of the deep sea pilot compared to the crew.

5. Discussion

This study offers valuable insights into ship safety on the North Sea as projected for 2030. However, several limitations must be acknowledged to ensure a balanced interpretation of the findings. These limitations arise from both methodological decisions and external factors that could affect the generalisability and accuracy of the results. Acknowledging these constraints provides a more nuanced understanding of the study's scope.

Single playthrough limitations

Most scenarios were conducted only once, which may impact the reliability of the findings. Playing each scenario a single time restricts the ability to account for variability in responses, which could be influenced by chance, context-specific factors, or individual participant characteristics. Without repetition, it is challenging to determine whether the outcomes observed are consistent and reproducible. This limitation suggests that the results may not fully reflect the range of possible responses, potentially affecting the study's overall reliability and generalisability. Consequently, this research should be regarded as exploratory in nature.

Additionally, some crew members from the "less experienced" merchant vessel team participated in multiple scenarios. This repetition may have introduced a learning and familiarity effect, making them more acquainted with the North Sea area and its wind farms than initially intended.

Cultural and role discrepancies among participants

Although some requested cultural backgrounds, such as Malaysian and Ukrainian, were represented, these were limited to individual crew members rather than providing a complete representation of their respective cultural dynamics. This limits the ability to generalise findings to broader cultural contexts.

Furthermore, one captain demonstrated a preference for assuming a role aligned with bridge resource management standards typical of a cruise line captain, rather than those expected of a merchant vessel captain. Despite reiterating the expectations for a merchant vessel captain during the simulation, this discrepancy may have influenced crew collaboration dynamics and affected the authenticity of the scenarios. As a result, the study's applicability to real-world maritime contexts could be limited.

Challenges in VTMon familiarity and role clarity

VTMon participants were not fully acquainted with the instruments and tools used in the simulations, as these differed from those they typically utilise. Additionally, the roles, responsibilities, and authority of the VTMon are not yet clearly defined. For some participants, this ambiguity led to frustration and confusion.

These challenges were occasionally reflected in the RSME scores, which measure mental effort. Instead of accurately representing cognitive load, the scores sometimes captured the participants' frustrations and struggles with unclear role expectations and unfamiliar tools.

Simulator usability issues

Participants encountered usability challenges with the simulators, particularly with the autopilot functionality. The autopilot systems differed from those typically used by participants, leading to occasional frustration, especially among skippers operating the part-task bridge simulators.

The limited immersive experience provided by the part-task bridges further contributed to these challenges. Difficulties in controlling visual elements and operating unfamiliar systems likely influenced the RSME scores, which may reflect these usability issues rather than the participants' actual mental effort or capabilities. Consequently, the skippers' experiences may not fully represent their real-world performance.

6. Conclusions and recommendations

6.1 Behaviour of ship crews

The first research question was:

1. What is the effect of the wind farms and increasing traffic density on the North Sea on the sailing behaviour of the ship crews?

The following conclusions are drawn related to the sailing behaviour:

Merchant vessel crews

In general, the objective results do not indicate that sailing in between or past the OWFs in the North Sea area reduces situational awareness. However, visual perception of objects or vessels during nighttime conditions can be challenging. This is worsened by light pollution from the wind farms, the coastline, and other objects. Radar or AIS is therefore essential for timely detection of vessels, particularly smaller ones like sailing yachts.
It is recommended to ensure that the OWF lighting, which complies with regulations and international agreements, minimizes potential distraction from other lights (e.g., vessels, the coast or other objects) and enhances the recognition of existing distinctive lighting, particularly by recreational users. Further research on the potential distraction caused by lighting, even when adhering to rules and regulations, is recommended.

The results of this study conclude that OWFs themselves are not perceived as problematic. The results show that merchant vessel crews consider cables and pipelines during anchoring procedures and view anchoring as a last-resort measure to prevent drifting into an OWF in case of an emergency. The increased traffic density, partly due to the OWFs, is perceived as a more significant safety concern. It results in vessels sailing closer together and reduces available manoeuvring space.

The threat of higher traffic density may require more capacity or specific support tasks from VTMon.
It is therefore recommended to explore the specific needs for vessel crews during high traffic density and convert this to VTMon capacity, task description and support systems.

Sailing yacht skippers

For sailing yacht skippers, restricted areas around OWFs are perceived as an additional challenge. These restrictions reduce route flexibility and force skippers to sail closer to large commercial vessels, which is perceived as risky and undesirable.

Crossing a TSS, particularly in the crowded and unpredictable area northwest of HKZ, is considered more challenging than navigating the passage for small vessels through HKZ. As a result, skippers prefer the passage for small vessels if the additional sailing distance is manageable.

The passage for small vessels of HKZ is experienced as relatively narrow. During adverse weather conditions, such as heavy weather, strong currents, or upwind sailing, more space is needed for tacking. In these cases, skippers prefer to sail north of the wind farm, where there is more sailing area. When using the passage for small vessels under restricted visibility conditions, skippers tend to stay as far to starboard side as possible to avoid encounters with other vessels. Depending on the wind and currents, skippers maintain a safe distance from the OWF to prevent drifting into restricted areas. AIS is regarded as essential for maintaining situational awareness in these conditions to increase safety awareness and safety. While having AIS is currently a precondition for sailing the small passageway of HKZ this was occasionally unknown for the sailors.

Given the conclusions above it is recommended to make passages attractive to use for yacht sailors from a safety point of view. This means that passages should be wide enough to sail through under different weather conditions. Second, yacht sailors should know if, when and where they can cross the parks through passages, and what kind of other ships they may expect. This may encourage them to use the passages. Third, it is recommended to increase the awareness of yacht sailors that AIS is obligatory when sailing through the wind farms. The use of AIS is important for their own safety, but also for other vessels.

6.2 Mitigating measures

The second research question was:

2. How effective are the mitigating measures?

The following conclusions are drawn related to the mitigating measures:

VTMon

The VTMon appears to be a helpful measure to guide ships while navigating between the OWFs and to provide assistance during incidents and accidents.

However, during high-demand situations, the span of control seems to be too large, resulting in focusing most attention to urgent incidents and neglecting the rest of the area.

It is therefore recommended to organise a back-up for the VTMon operator for emergency situations, like a duty officer. The back-up can take over the monitoring of the area, while the initial operator takes care of managing the incident.

The specific tasks and responsibilities of the VTMon are not fully described and clear to the future operators. This lack of clarity affects the ability to perform the role effectively.

It is therefore recommended to further describe the VTMon operators tasks and responsibilities and train them accordingly.

Shifts of 1.5 hours seem to be acceptable for operator performance. However, longer shifts were not explored in this study.

The systems provided during the simulations are insufficient to efficiently support task performance. However, the current available systems for VTS were not fully present. A more representative set-up of the VTMon desk might have led to a different conclusion.

It is therefore recommended to at least apply the regular VTS support systems to the future VTMon desk. Additionally, it is recommended to define the required support systems to perform this role, do a gap analysis with the current VTS systems and add any missing functionality.

An additional VTMon simulation scenario is recommended to evaluate the efficiency of the operator role as intented and to identify missing support functionality. At the same time, various shifts can be evaluated as well.

Emergency Response Towing Vessel (ERTV)

The deployment of ERTV seems to be an effective measure during incident management. Experienced crews, like in the scenario runs, are able to adopt a proactive approach by monitoring the area through VHF communication and communicate effectively with ERTV, VTMon, and other vessels.

However, there is a risk that the ERTV may not arrive on time due to sailing distances or weather conditions that prevent shortcutting through an OWF.

It is recommended to optimise the positioning of the ERTVs in the North Sea area to prevent long ETAs. Criteria could be, for example, a minimum response time for the whole area or to define critical spots where shorter response times are needed.

Deep sea pilot

A deep sea pilot appears to be a valuable safety measure when navigating in between OWFs. Knowledge on the local characteristics of the North Sea makes it easier to make the right decisions to prevent collisions. Moreover, the experience and communicative skills of the deep sea pilot helps with communicating with parties like the VTMon and ERTV during crisis situations. However, having a deep sea pilot on board is not mandatory and therefore regularly neglected for financial reasons.

It is therefore recommended that additional information on the use of a deep sea pilot, as an effective safety measure when sailing through wind farms, is provided. Giving clarity on the costs and benefits of having a deep sea pilot on board in the North Sea could persuade more parties to consider taking a deep sea pilot on board.

References

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List of abbreviations

Abbreviation	*Explanation*
AIS	Automatic Identification System
CPA	Closest Point of Approach
DO	Duty officer
ECDIS	Electronic Chart Display Information System.
ERTV	Emergency Response Towing Vessel
ETA	Estimated Time of Arrival
Events	Particular moments in simulation runs initiated by simulator operator evaluator or delegates. Events are used to describe the simulation run in a sequential order.
HKZ	Offshore wind farm Hollandse Kust Zuid
HKN	Offshore wind farm Hollandse Kust Noord
HKW	Offshore wind farm Hollandse Kust West
LOA	Length Over All
MOSWOZ	Monitorings- en Onderzoeksprogramma Scheepvaart veiligheid Wind op Zee. Offshore Wind Energy Shipping Safety Monitoring and Research Programme.
NM	Nautical Mile. One nautical mile equals 1.852 metres

Abbreviation	*Explanation*
NUC	Not under command. A vessel which through exceptional circumstances is unable to manoeuvre as, required by the COLREGs.
OWF(s)	Offshore wind farm(s)
RSME	Rating Scale Mental Effort
RWS	Rijkswaterstaat, an executive agency of the Ministry of Infrastructure and Water Management"
TAS	Threat Assessment Scale
TAT	Towing Assistance Team
TCPA	Time to Closest Point of Approach
Transit Passages	Passages trough an offshore wind farm intended to be used by ships <46 meter.
TSS	Traffic Separation Scheme
VHF	Very High Frequency, referring to the radio frequency range between 30 MHz and 300 MHz, commonly used for maritime communication and broadcasting.
VTMon	Vessel Traffic Monitoring. The process (or methodology) of monitoring ship movements in and around offshore wind farms.
VTS	Vessel Traffic Service
UT	University of Twente

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