SPOWTT
Improving Safety and Productivity of Offshore Wind Technician Transit

SPOWTT
FINAL PROJECT REPORT

THE SPOWTT STORY, FINDINGS AND NEXT STEPS

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Contents

Glossary

Term / acronym	Meaning
BMO	BMO Offshore (consortium partner)
CMS	Condition Monitoring System
Db	Database
EF	Earth Fixed
IR	Illness Rate
JONSWAP	Joint North Sea Wave Project
KRIMA	SGRE in-house health & safety reporting system
Gamma	Peak enhancement factor
HTML, CSS, JS, Python	Programming languages
Hs	Significant Wave Height
LCG	Longitudinal centre of gravity
LID	Lynn & Inner Dowsing Wind farm
Lpp	Length between perpendiculars
MARIN	Maritime Research Institute Netherlands (consortium partner)
MSI	Motion sickness indicator
MTI	Motion sensor model from Xsens
Mo	Zeroth order spectral moment
µ	Wave incidence angle
µship	Ship heading
ODSL	ORE Catapult Development Services Ltd. (consortium partner)
O&M	Operations & Maintenance
RAO	Response Amplitude Operator
SBC	Ship Behaviour Calculator
SDA	Significant Double Amplitude
SF	Ship Fixed
SMC	Specialist Marine Consultants (consortium partner)
SGRE	Siemens Gamesa Renewable Energy (consortium partner)
Std	Standard Deviation
SVG	Scalable Vector Graphics
TF	Trim flap angle
TNO	Netherlands Organization for Applied Scientific Research (consortium partner)
Tmean	Mean Draft
TRL	Technology Readiness Level
Tp	Peak wave period
Tz	Zero-upcrossing wave period
UoH	University of Hull (consortium partner)
VBB	Vessel Black Box VMMS of BMO
VDV	Vibration Dose Value
VMMS	Vessel Motion Monitoring System
Vship	Ship speed

1 Project Fundamentals

Introduction

SPOWTT stands for "improving the Safety and Productivity of Offshore Wind Technician Transit". It is a complex, multidisciplinary, multinational project which aims to address an important health and safety issue for marine transit of technicians working in offshore wind operations and maintenance (O&M). The central objective of the project is to develop an evidence-based, open access tool to support the 'sail/no sail' decision process for marine coordinators authorising O&M technician work. Weather, sea state and vessel motion have been monitored alongside psychological and physiological measures to assess the complex relationships between environmental conditions of transit and the impact on technicians. These data have been combined to create a model, and then a tool, that can support the site operations teams to 1) launch, 2) not launch, or 3) to launch with certain control measures. This project has produced a range of open access information that can be utilised by marine coordinators in their decision-making throughout the Offshore Wind industry. The resulting tool allows decisions to be made which are grounded in evidence of the human impact of sailing in different conditions.

Funding body

The SPOWTT project is funded in part by the European Union's Horizon 2020 research and innovation programme under grant agreement No 691732. This public funding is managed in the UK by the Department for Business, Energy and Industrial Strategy (BEIS) and in the Netherlands by RVO. In addition, one project partner received funding from the Green Port Growth fund.

Objectives

The original project objectives are summarised as:

- Identify the hazards and quantify the physiological and psychological impacts of technician transit in a crew transfer vessel (CTV).
- Understand the impact of technician experience in transit on vessel utilization and technician productivity, health and wellbeing.
- Define a common framework for the industry to match CTVs to the environmental conditions of offshore windfarms by producing an open access decision making model.
- Define safe environmental limits for a vessel and propose control measures to minimise in-vessel impacts through the analysis and interpretation of the psychological and physiological data associated with crew transport.
- Support development of the first commercially available tool to show the market how this model can be integrated with other existing software, planning, and decision support tools.
- To develop a deeper understanding of, and responses to, the wellbeing and productivity of people who work offshore.
- Demonstrate and validate in a number of different wind farms application of the decision-making model.

Project partners

In order to achieve the objectives of the project, various companies were hand-picked to deliver the expertise in various key fields. These 7 businesses are outlined in Figure 1.1, along with their main contribution to the project. Further detail on how these participants were involved in each Work Package is described later.

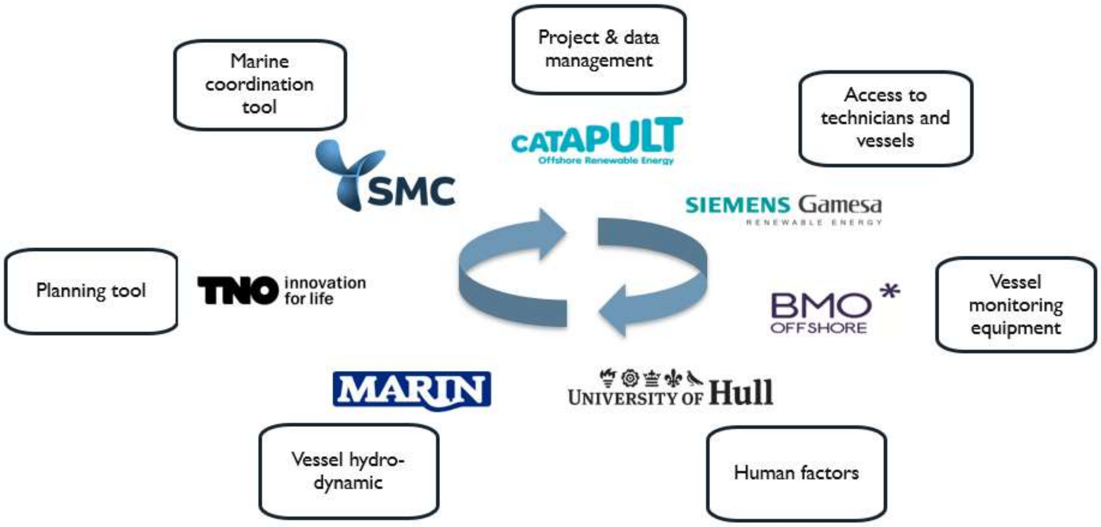


Figure 1.1 - Project Participants

Fundamentals of the model

At the core of this project is the need for a single model to describe the relationship between basic information about a planned transit and a resulting likelihood of seasickness. The construction of such a model can be split into two key phases as outlined in Figure 1.2 below: <u>Vessel Hydrodynamics</u> and <u>Human Factors</u>.

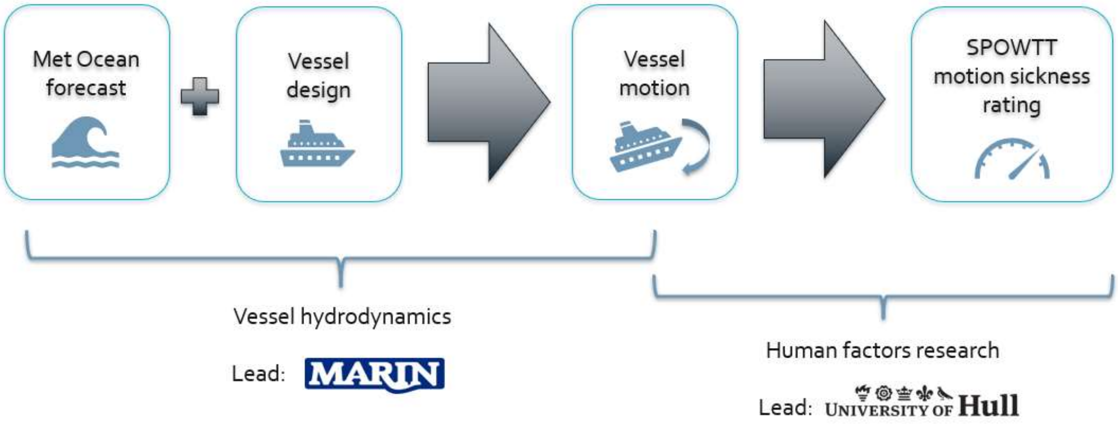


Figure 1.2 - The Model

These two aspects of the project will be explored further in later chapters, along with explanation of how the model was implemented and development of the resulting tools.

Work Packages

The project was split into eight work packages, all with a formal set of objectives and participating members. These are summarised in the following tables.

Work Package 1 – Project Management	**Lead**: ODSL
• Ensure the technical objectives of the project are achieved by coordinating the technical activities between Work Packages and over the different phases of the project, within budget and on time; • To ensure that all project deliverables and milestones are delivered as planned; • To ensure effective communication across the consortium; • To communicate all project outcomes to the Managing Authorities as appropriate; • Deliver all periodic and final reports on time; and • To ensure financial transparency and accountability for all public funds.	

Work Package 2 – Data Management	**Lead**: ODSL / University of Hull (UoH)
• Development of a suitable tool for the handling and anonymisation of appropriate data being generated within the SPOWTT project. The analysis of data requirements necessitates the development of a bespoke data input and analysis tool to enable development of the decision support tool.	

Work Package 3 – Vessel hydrodynamics	**Leads**: MARIN / University of Hull / BMO
• Supply full-scale data to build the modules of sea-ship interaction and ship-human interaction for use in the decision support tool. • Hydrodynamic analysis	

Work Package 4 – Human factors field study	**Lead**: University of Hull
• Provide empirical evidence of the impact of the CTV transit process on technicians and crew. • Preliminary objectives include an analysis of existing data sources of crew activities (pre, during and post transit) and an analysis of formal and informal operating procedures and practices. • These data will then support the design of a valid, two-phase field study, which is the central focus of WP4. The main objective of the field study is to quantify the psychological and physiological impacts of the transit process. • Analysis of the field study data will allow the identification and selection of the factors which (a) can be evidenced to predict productivity, safety and well-being outcomes and (b) can be included in a model for WP5.	

Work Package 5 – Decision making model	**Lead**: University of Hull
• Combine vessel, environmental and human (psychological / physiological) factors to produce advice for a planned transit on safety and the likely productivity of the technicians post transit. This data will be combined in a model that describes the relationship between them.	

Work Package 6 – Design & Test control measures	**Leads**: SGRE, MARIN
• To identify and test control measures that can reduce in a measurable way the negative impacts of the transit on technicians and produce recommendations for how these could be integrated into operating procedures.	

Work Package 7 – Develop tools and practices to improve operational productivity	**Leads**: TNO, SMC, BMO
• Put the decision-making model developed under WP5 into a tool that can be used in an operational environment and to demonstrate it to TRL7. The tool will enable: • Optimal vessel fleet selection. The existing TNO tool for O&M strategy selection will be upgraded according to the results of WP5. By including detailed models of vessel hydrodynamics and the effect on human performance, long-term O&M costs can be estimated more accurately, hence allowing the optimization of long-term decisions on vessel fleet selection. • Higher confidence in the short-term decisions. By including current and forecasted environmental conditions to the model developed under WP5, marine coordination and especially day-to-day decisions on launching CTVs will be enhanced by a user-friendly tool that will provide insight on the anticipated results (vessel motions, seasickness etc.) of the decision-making.	

Work Package 8 – Dissemination & Exploitation	**Leads**: ODSL, SGRE, TNO, SMC
• To develop an exploitation plan for the foreground knowledge developed • To disseminate the key results of the project through numerous channels • To organise dissemination events for the benefit of the offshore wind sector	

2 Vessel Hydrodynamics

This section of the report focuses on the work delivered by the project team under Work Package 3, primarily by MARIN, BMO and The University of Hull. It constitutes building the front end of the model to describe how to predict vessel motion.

2.1 Full scale measurements

2.1.1 Vessel Monitoring

Throughout the SPOWTT project, the BMO Vessel Motion Monitoring System (VMMS) has been gathering data on vessel motions for two purposes:

1. validation of the hydrodynamic model (this chapter); and
2. to aid the development of the human factors model as described in Chapter **Error! Reference source not found.**.

A measurement kit has been developed and deployed on 14 different vessels from 5 distinct operators. These vessels ranged from small 40 tons CTVs with a relatively short hull length (15 m) towards larger 80 tons vessels of 27 m length overall. The vessels were operated on a total of 5 different wind farms, to ensure a large spread of different measurements due to different sea climates and seasonal variety. The measurement campaigns completed are described in Table 2.1 below.

Phase	Vessels	Time period	Description
Pilot	1	2017	Pilot trial
Phase 1	7	2018+2019	Measurement Campaign
Phase 2	10	2019	Measurement Campaign
Extra	1	2020	Support for On-board decision tool testing

Table 2.1.1: Overview of full-scale measurement campaigns

A schematic of the kit is displayed in Figure 2.1. The following parameters have been monitored on the vessel:

- GPS location of the vessel (longitude, latitude);
- Absolute speed of the vessel;
- Heading of the vessel;
- Translational accelerations in 3D;

- Angular accelerations around the 3D axes; and
- Vessel attitude (pitch, roll, yaw).

The former three parameters (location, speed, heading) have been recorded at a frequency of 1 Hz. The latter parameters (accelerations and attitude) were recorded at 40 Hz. In total, 2071 days of operation have been monitored. It is estimated that this has resulted in ~2500 transit trips between port and wind farm.

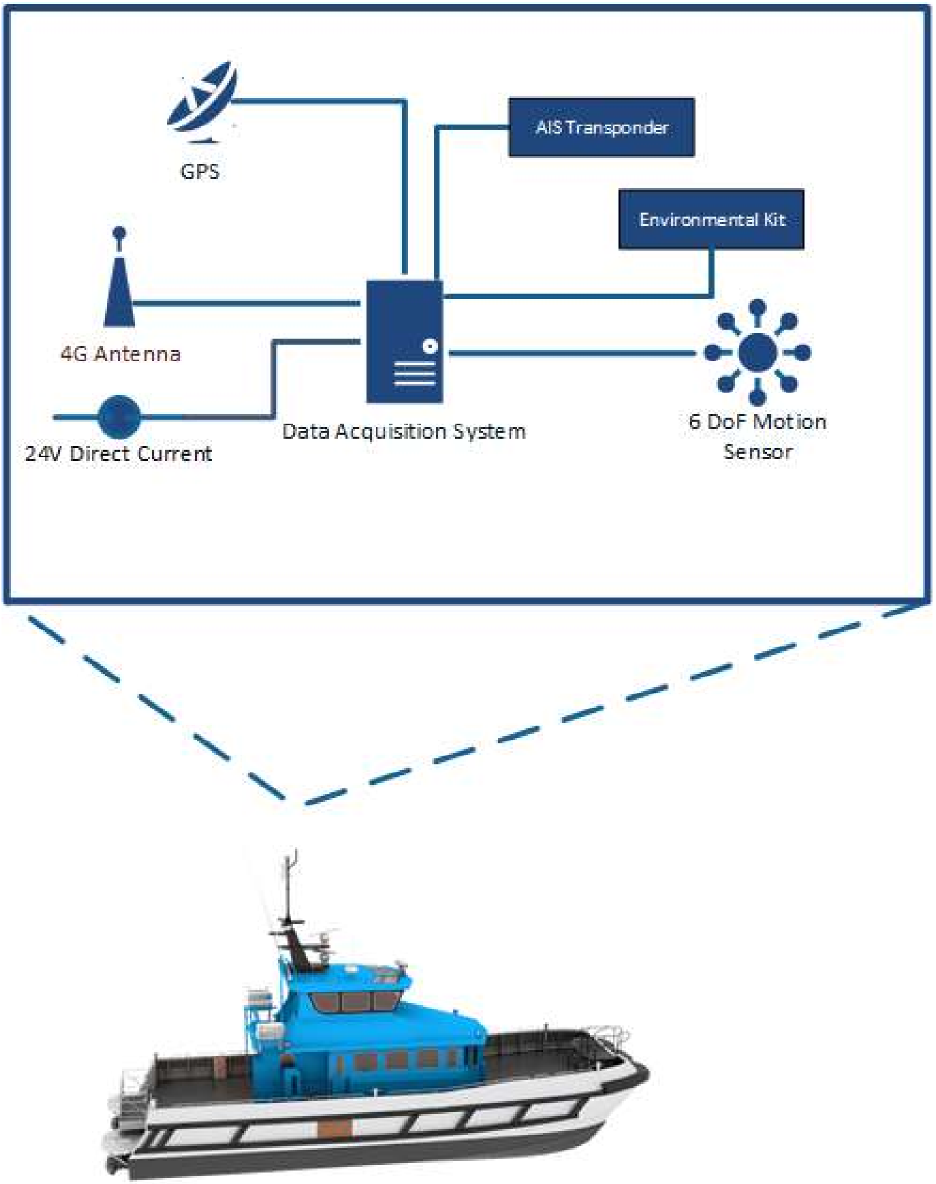


Figure 2.1 - Schematic overview of the Vessel Motion Monitoring System (VMMS)

2.1.2 Data application

The collected data was used to create a general overview of:

1. Vessel and journey characteristics (journey time, speed, location, motions)
2. Weather conditions during transits
3. Seasickness indicators during the journeys.

As basis for the tool definitions (Chapters 4 and 5) it is vital to be have a clear picture how the vessels currently operate. Vessels were equipped with BMO measurement systems. Data from those measurements is analysed. This is done for three ships over a period of one to three months.

For these vessels information pages are made per travel day. These pages include sailed track, vessel motions and vessel accelerations. Based on the accelerations 3 sickness indicators are calculated:

1. MSI (Motion Sickness Indicator, based on ISO MSI (ISO 2631-1:1997(E) Annex D)),
2. VDV (Vibration Dose Value), based on ISO 2631-1:1997(E),
3. IR (Illness Rate). The Illness rating has been developed together with TNO, MARIN, the Dutch Navy and Feadship and is unfortunately not public. However, the main concept is identical to the ISO MSI (ISO 2631-1:1997(E) Annex D) but the habituation is more advanced than sqrt(t). In the first hours of a transit trip, the more advanced exposure function is nearly identical to sqrt(t). The horizontal accelerations are also accounted for. This is done in a similar way to the methodology in section 6.5 of the aforementioned document. It should also be noted that the advanced exposure function is relatively limited for the CTVs when they are sailing at higher speeds.

The progress of these indicators are presented over the journey. The vessel information pages are intended to be a first indication of the vessel behaviour and the possible effect on the well-being of the passengers. Also, they can help to identify days where a vessel returned to shore with possible comfort related issues.

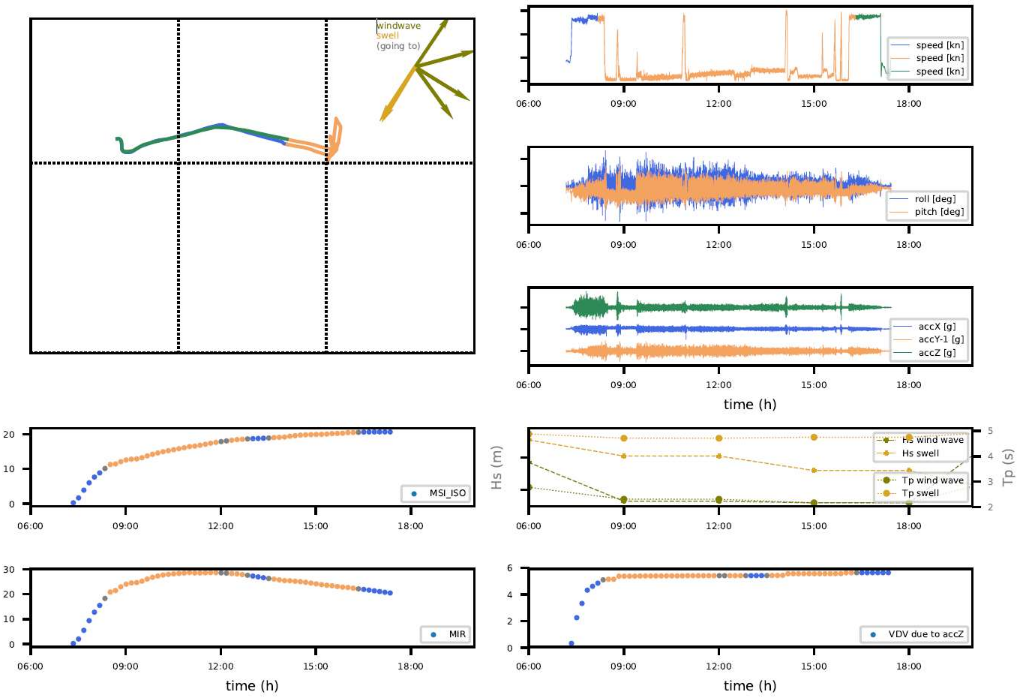


Figure 2.2: Example overview of one CTV travel day.

Figure 2.2 shows an anonymised example of a vessel information page from one of the vessels. The different colours within the individual plots represent the travel to and from the field and the time in the field. In the MSI, VDV and IR graphs the grey dots indicate transition periods (partly inside and partly outside the field).

The figure shows a typical journey where the outward journey was rough (z-accelerations) which is reflected in all three sickness indicators.

The investigated data indicates that, for the outward journeys, the three sickness indicators are highly correlated. They were also compared with a subset of the human questionnaires in Chapter 3 to investigate the possible correlation. However, none of the three showed a significantly better correlation than the others. For the onboard tool discussed in Chapter 4 we use the MSI. This is the simplest and most widely used motion sickness indicator.

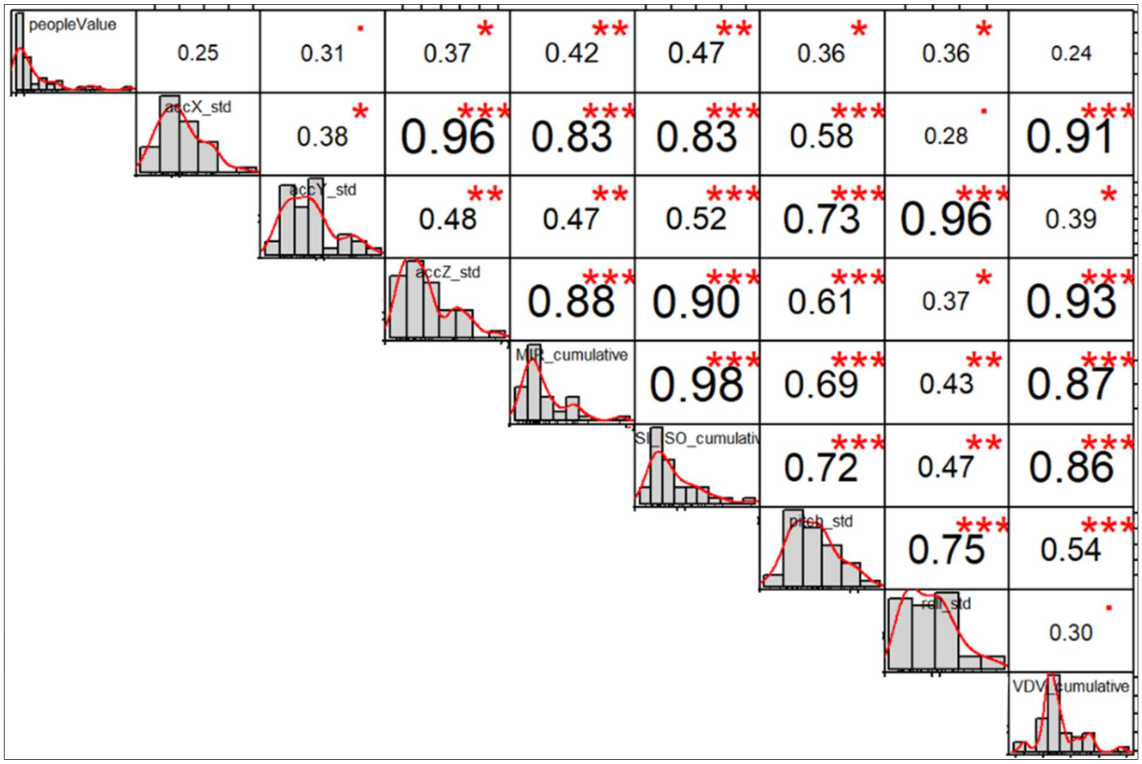


Figure 2.3: First indication of correlation between the human seasickness indications from questionnaires, various vessel motions and motion sickness equations. Based on a limited set of data. Std means standard deviation and cumulative indicates the cumulative value over the whole outward or return trip.

2.2 Numerical Methods - simulations

The hydrodynamic performance of the CTVs is calculated by dedicated existing hydrodynamic software at MARIN. The applied numerical approach is described in this section.

The objectives of the hydrodynamic numerical simulations are:

- Provide vessel motion response and human seasickness for a range of typical CTVs as input for the TNO planning software.
- Calculate realistic vessel motion response for a wide range of realistic environmental conditions consisting of current, waves, wind and swell.
- Calculate vessel motion response for various speeds in order to predict effects of voluntary speed losses on human seasickness and take this into account in the planning.

These numerical simulations and their validation are described in the present section. The calculated vessel motions are validated based on full scale measured vessel motions and results of model tests.

Figure 2.4 shows a typical CTV in the real (full scale) world and in the virtual simulated world.

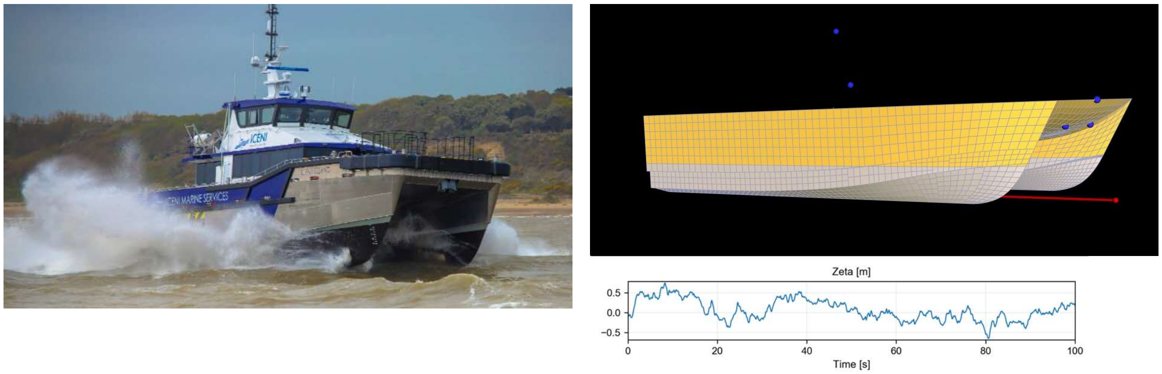


Figure 2.4: Typical CTV. Left: real, full scale world. Right: virtual, simulated world.

2.2.1 General procedure for validation of seakeeping tool

The following reasoning provides guidance in constructing a procedure for seakeeping simulations which can be used for the planning of operation and maintenance (O&M):

- The operability of transit journeys is determined using a database of motion RMS (Root Mean Square) values. Note the commonly applied Significant Double Amplitude (SDA) is equal to 4 times the RMS (SDA = 4.RMS). The definition of the SDA and RMS values based on numerical frequency domain analysis is given in Appendix 3.
- RMS values are calculated from motion RAO (Response Amplitude Operator) values in combination with sea and swell wave spectra.
- RAOs can be calculated using a ship motion simulation code, such as the frequency domain program SHIPMO or the time domain program PANSHIP.
- PANSHIP is based on a semi-nonlinear panel method to predict hydrodynamic loads on fast ships. An interesting feature of PANSHIP for CTVs is that it accounts for the hydrodynamic effects of lifting devices, such as foils and trim flaps.

Figure 2.5 presents the procedure reflecting the above reasoning, more or less in reverse order:

- The block ‘CTV’ represents the input data for PANSHIP: hull geometry (lines, panels), main particulars (loading condition and stability data) and appendages data. The analysed vessels and corresponding input parameters are described in Appendix 2. Reliable input data is essential for the accurate modelling of the vessel under consideration.
- The ‘PANSHIP’ block represents the PANSHIP calculations: once the CTV input data is read, time domain simulations are performed for a range of ship speeds, wave directions and wave frequencies. The resulting time traces of the ship motion response (in 6 degrees of freedom) are kept for further processing.
- The ‘RAO db’ block represents a database of ship motion response RAOs: the time traces calculated by PANSHIP are subjected to a harmonic analysis. The resulting first order coefficients give the amplitudes and phases of the motion responses (the output signals) with respect to the incoming wave at the ship centre of gravity (the input signal).
- The ‘Wave statistics’ block represents a database of sea states in terms of wave power spectrum density distributions, in short ‘wave spectra’. These wave spectra are characterized by parameters such as significant wave height, peak wave period and peak wave direction. For our purposes, we use the JONSWAP (Joint North Sea Wave Observation Project) wave spectrum formulation. The environmental conditions applied in the simulations are described in Appendix 2.
- The ‘Ship hydro transit db’ block represents a database of RMS values of vessel motion response and accelerations. The RMS is obtained by combining a motion RAO with a wave spectrum according to the following equation:

  $$S_x(\omega, \Theta) = S_\zeta(\omega, \Theta) . H^2(\omega) . d\omega$$

  $$RMS = \int_0^\infty S_x(\omega_0) \mathrm{d}\omega_0$$

  In this equation, we find the following quantities:

  - $S_\zeta(\omega, \Theta)$ is the wave spectrum density depending on the wave frequency ω and direction θ;
  - $H(\omega)$ is the amplitude of the motion response, also depending on the wave frequency ω;
  - $S_x(\omega, \Theta)$ is the motion response spectrum density, also depending on the wave frequency ω and direction θ.

  The spectral frequency domain analysis calculation approach is described in Appendix 3.

  The calculated vessel motion response signals are listed Appendix 2. The ‘Ship hydro transit db’ also contains the seasickness index.
- The ‘Weather data’ block represents the actual weather input data for the O&M tool.
- The ‘O&M tool’ block represents the decision support tool for O&M. It accepts input data from the ‘Ship hydro transit db’ and ‘Weather data’ blocks, and then it calculates the relevant quantities or parameters (such as seasickness) to make the ‘go / wait’ decision.

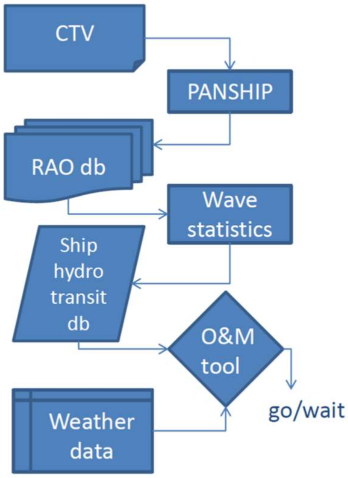


Figure 2.5: Outline of O&M decision support tool

In view of the steps in the above procedure, the validation framework should allow for a comparison of simulated and measured motion responses at two levels:

- At the 'frequency level', where we look at the spectral correlation (or cross spectrum) of vessel motions and accelerations. This way of comparing simulations and measurements is presented in schematic form in Figure 2.6
- At the 'sea-state level', where we look at the SDA values of vessel motions and accelerations. This way of comparing simulations and measurements is presented in schematic form in Figure 2.7.

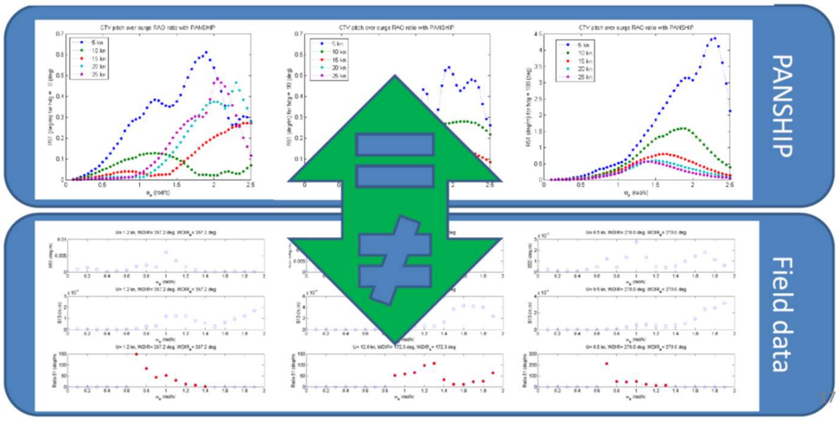


Figure 2.6: Comparison of simulated and measured motion responses at 'frequency level'.

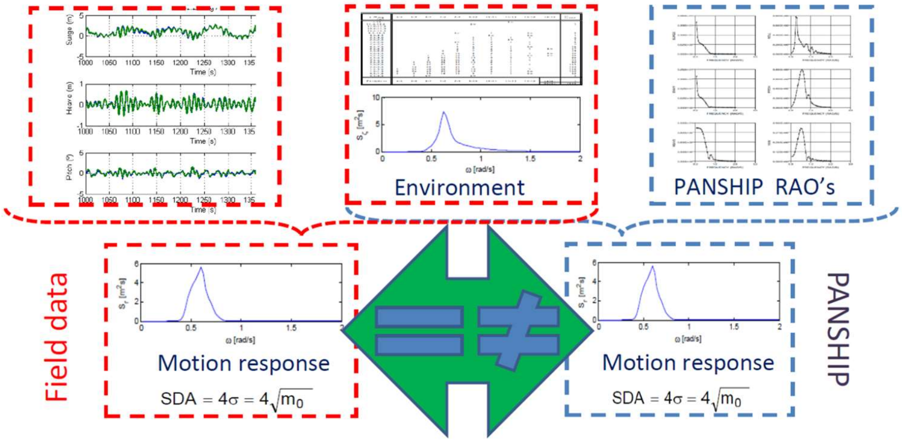


Figure 2.72: Comparison of simulated and measured motion at 'SDA level'.

Since the simulations are based on the assumptions that

1. the ship heading with respect to the waves – or, equivalently, the wave direction with respect to the ship sailing at a fixed course – is constant;
2. the ship speed is constant;
3. the wave conditions are constant

we must find data from our measurements that satisfy similar conditions:

1. a more or less steady ship heading;
2. a more or less steady ship speed;
3. more or less steady wave conditions.

This issue is addressed in Section 2.2.2.

Figure 9 (1-3) show examples of just three of several contour plots created showing the pitch SDA values in an irregular sea state for three CTV vessels. The significant wave height (H_s) is 1 m and the vessel speed (V_{ship}) is 25 kn. The horizontal axis corresponds to the peak wave period (T_p) and the vertical axis corresponds to the ship heading (μ_{ship}). The highest pitch SDA values are observed in head and following seas and at the lower peak wave periods, which correspond to short waves (T_p=4 s corresponds roughly to 30 m wave length).

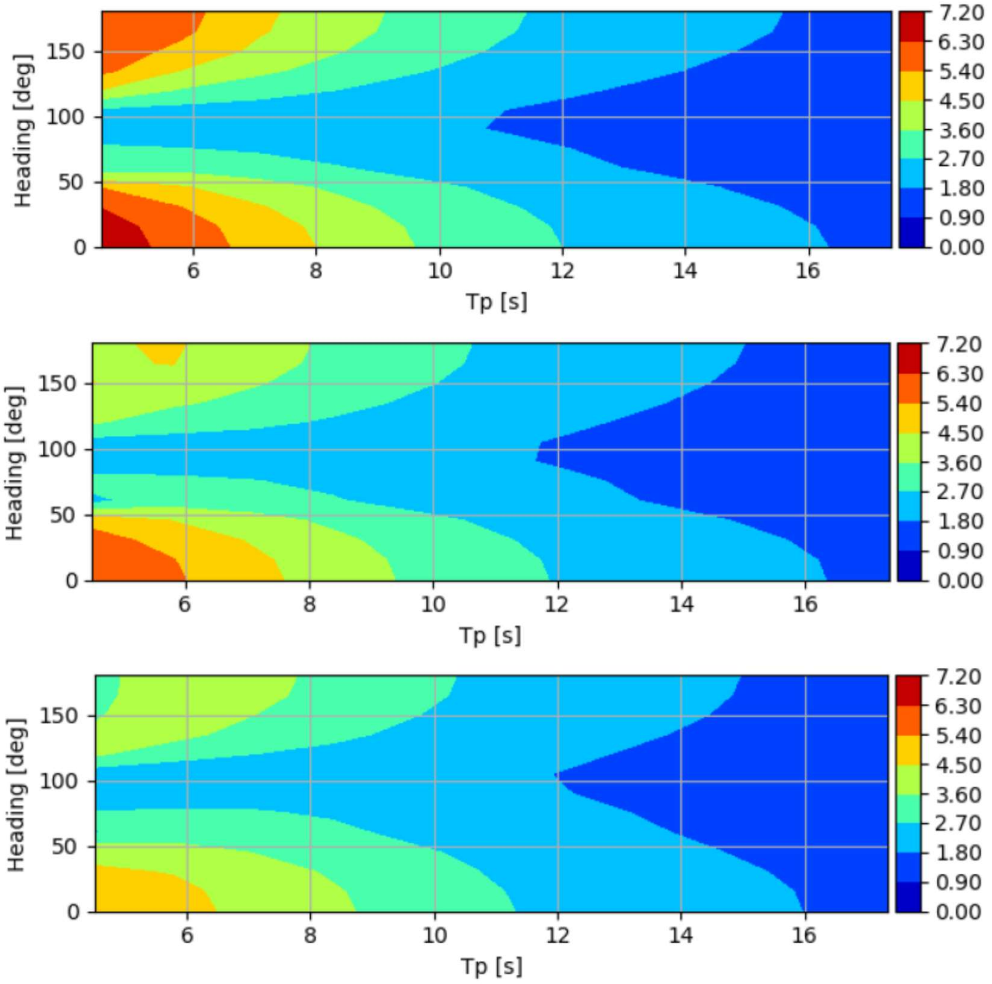


Figure 2.9 (1-3): Contour plots of pitch SDA values in irregular seas, based on PANSHIP-linear simulations in regular waves. V_{ship} = 25 kn, H_s = 1 m. From top to bottom: CTV-13m, CTV-14m, CTV-15m.

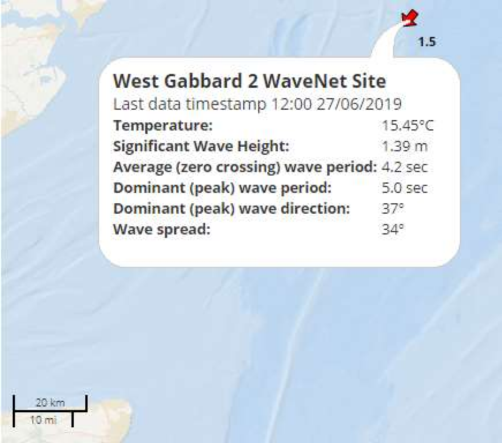
Figure2.10: Typical CTV in operation.

2.2.2 Selection of measured data for validation

The validation of the numerical method PANSHIP relies heavily on the availability of a sufficient amount of high quality data. Wave data may be obtained from

- wave buoys: the main disadvantage of wave buoys is that they provide data for specific locations only;
- satellite data post-processed using mathematical-physical models: the Copernicus 027 database provides data on a dense grid, both in space and in time.

Figure 2 presents a comparison of West Gabbard 2 (location shown in Figure 31) wave buoy data collected in December 2018 versus Copernicus 027 data. There is good overall agreement for the significant wave height (H_s) and the wave period (T_z and T_p).


West Gabbard 2 WaveNet Site
Last data timestamp 12:00 27/06/2019
Temperature: 15.45°C
Significant Wave Height: 1.39 m
Average (zero crossing) wave period: 4.2 sec
Dominant (peak) wave period: 5.0 sec
Dominant (peak) wave direction: 37°
Wave spread: 34°

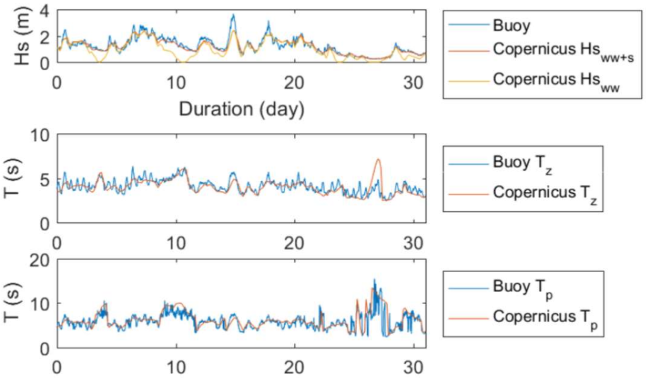


Figure 31 (left): West Gabbard 2 wave buoy location. Figure 2.12 (right): Comparison of wave data in December 2018. West Gabbard 2 wave buoy data versus Copernicus 027 data. Top: significant wave height. Middle: zero-upcrossing wave period. Bottom: peak wave period.

For this validation study we selected a nearby offshore wind farm with a location in relatively open sea (shown in Figure3), without effects from the shore and with a relatively long travel distance and time.

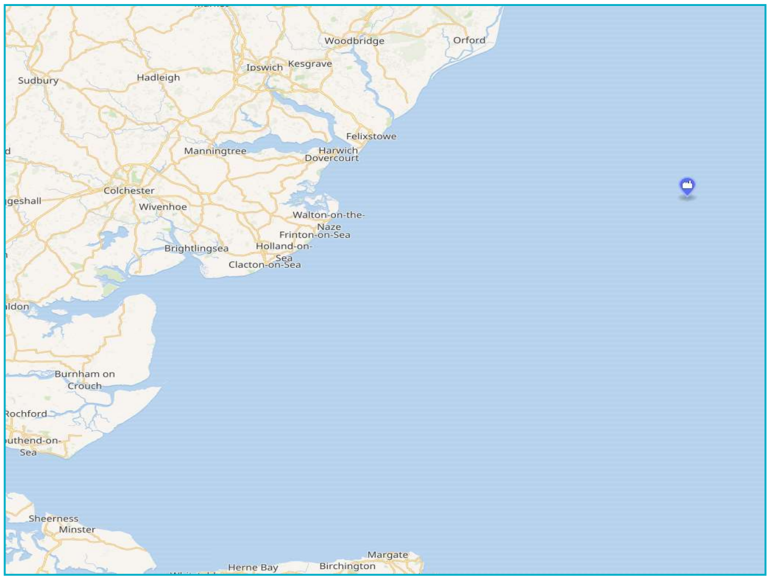


Figure 2.13: Location of selected offshore wind farm.

Vessel motion data is collected by SPOWTT consortium member BMO Offshore. Onboard measurements were collected by BMO's VMMS as described in section 2.1.1 for a large number of CTVs. For this validation data for 2 vessels and 100 voyages was used. The sampling frequency for the motions is 40 Hz. The measurements give position, speed- and course over ground, roll motion, pitch motion and accelerations. Figure 4 shows an example of vessel measurement data.

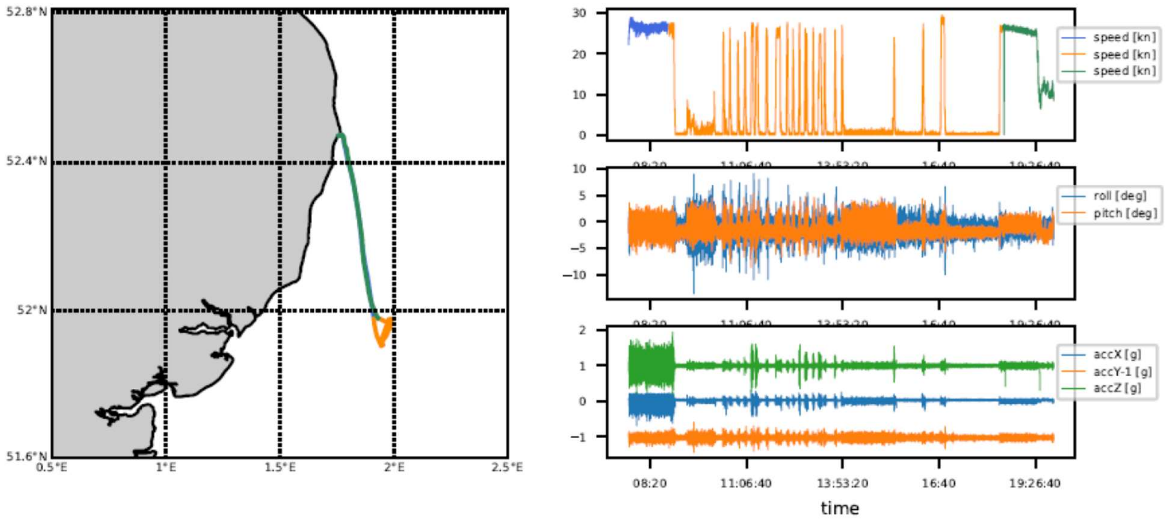


Figure 2.14: Example of data measured onboard a typical CTV. Left: trajectory from harbour to wind farm and back. Right, from top to bottom: ship speed; roll and pitch motions; longitudinal (accX), transversal (accY) and vertical (accZ) accelerations.

The analysis procedure consists of two phases exploration and batch processing.

The exploration phase consists of the following steps:

- load the measured data;
- load the weather data from the Copernicus 027 database;
- manually select a trip;
- analyse this trip.

The batch processing phase consists of the following steps:

- read the statistics file;
- re-run the analysis;
- run the comparison with journeys simulated by PANSHIP.

Figure 5 shows a screenshot from a Matlab tool created by MARIN, which enables the user to identify a 'steady speed and heading' time interval for a selected trip and to extract the corresponding measured data.

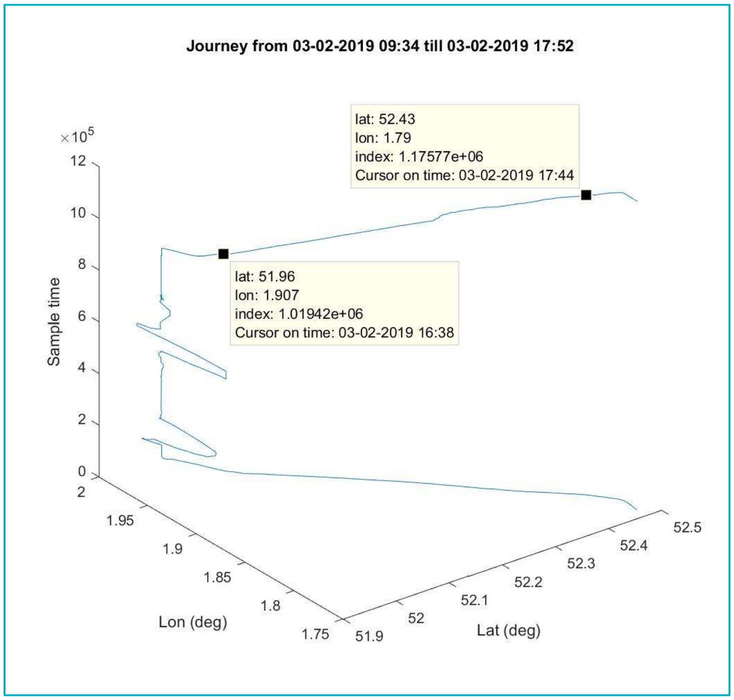


Figure 2.15: Screen shot of Matlab tool for identification of a 'steady speed and heading' interval for a selected trip and for extraction of corresponding data.

2.2.3 Sea state components and directional spreading

An important aspect in the analysis is the recognition that in general a sea state consists of multiple sea state components. In this analysis we distinguish

- wind sea;
- primary swell;
- secondary swell.

Figure 416 shows a typical example of the energy spectrum density distributions of these three wave components.

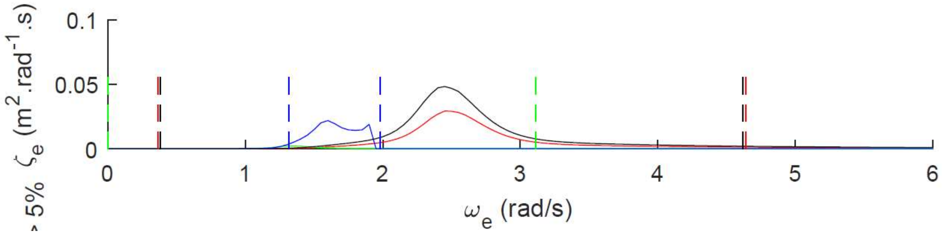


Figure 416: Example of energy spectrum density distributions for various wave components given with respect to encountered frequency around the mean direction ($\cos^{2s}$ spreading formulation WAFO [1]). Blue: wind sea. Red: primary swell. Green: secondary swell.

Another important aspect in our analysis is the recognition that in general waves do not come from a single direction: in reality, there is directional spreading, which varies over the wave frequency range.

Figure17 presents the directional spreading for the three sea state components wind sea, primary swell and secondary swell.

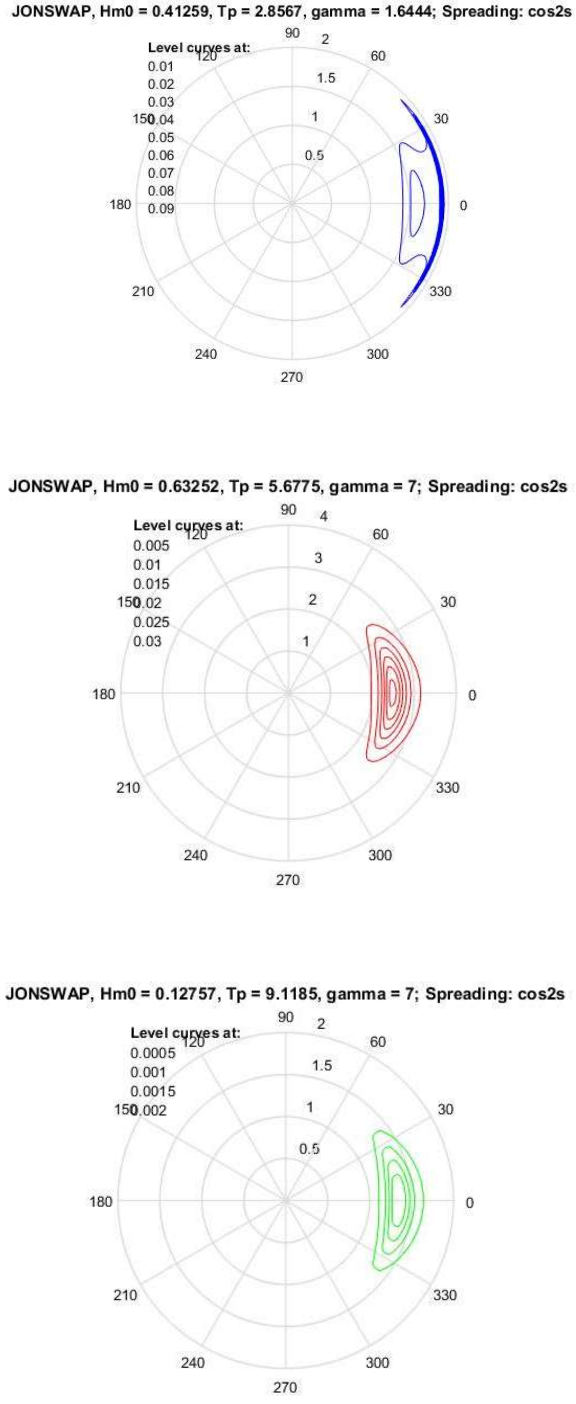
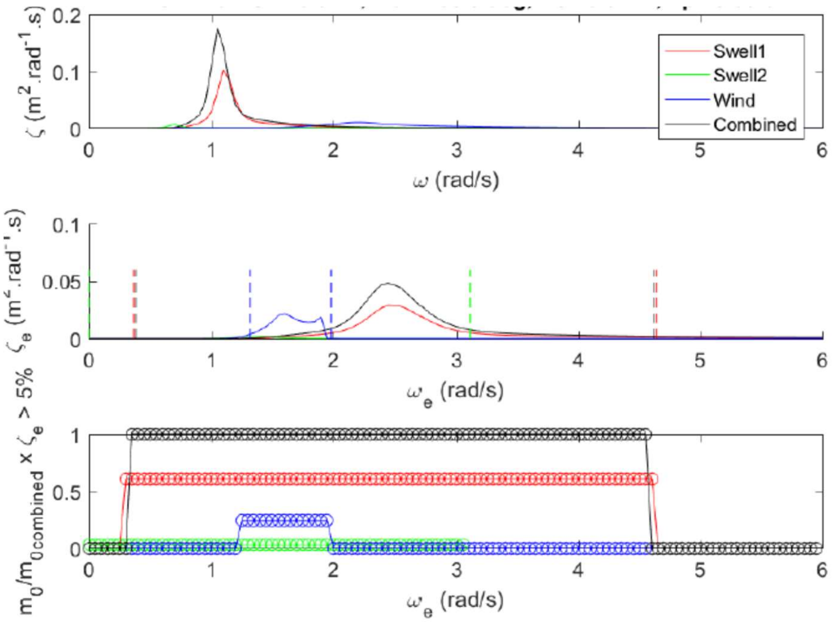


Figure2.17: Directional spreading for various wave components. From top to bottom: wind sea; primary swell; secondary swell.

Figur18 shows an example of power spectrum densities of various sea state components encountered during a simulated transit.



```
              mu_deg      Hs_m       Tp_s        m0_SI
              ______    ________    ______    _________

Swell1        144.76    0.63252     5.6775     0.023753
Swell2        177.54    0.12757     9.1185    0.0010117
Wind          275.36    0.41259     2.8567     0.009289
Combined      155.28    0.81012     5.9503     0.038997
```

Figure 2.18: Power spectrum densities of various sea state components in transit condition. Results apply for vessel speed 26.3kn, heading 155.3deg, significant wave height 0.81m and peak wave period 5.95s. From top to bottom: Power spectrum densities as function of wave frequency. Power spectrum densities as function of encounter frequency. Ratio of component-wise zeroth order moment to combined zeroth order moment. Parameters of sea state components. Wind = wind sea; Swell1 = primary swell; Swell2 = secondary swell; Combined = Wind + Swell1 + Swell2.

2.2.4 Results and discussion

Figure 519 shows the power spectrum density of the motion response, both measured (black dotted line) and calculated (coloured solid lines). The level of agreement is reasonable at best. Figure 2.20 shows: power spectrum density functions (PSD; blue lines) of the vertical (Acc-Z; left) accelerations and roll motions (Roll; right). The overlapping green and red lines show the range of frequencies of the swell and sea wave spectra respectively. These results show the importance to distinguish between the various components in a sea state: wind sea, primary and secondary swell each contribute to different parts of the vessel motion response spectrum. The peaks in the motion response are generally linked to a main wave frequency component. However, there is quite a lot happening outside the main wave frequent component: in roll, a clear low frequent response can be observed.

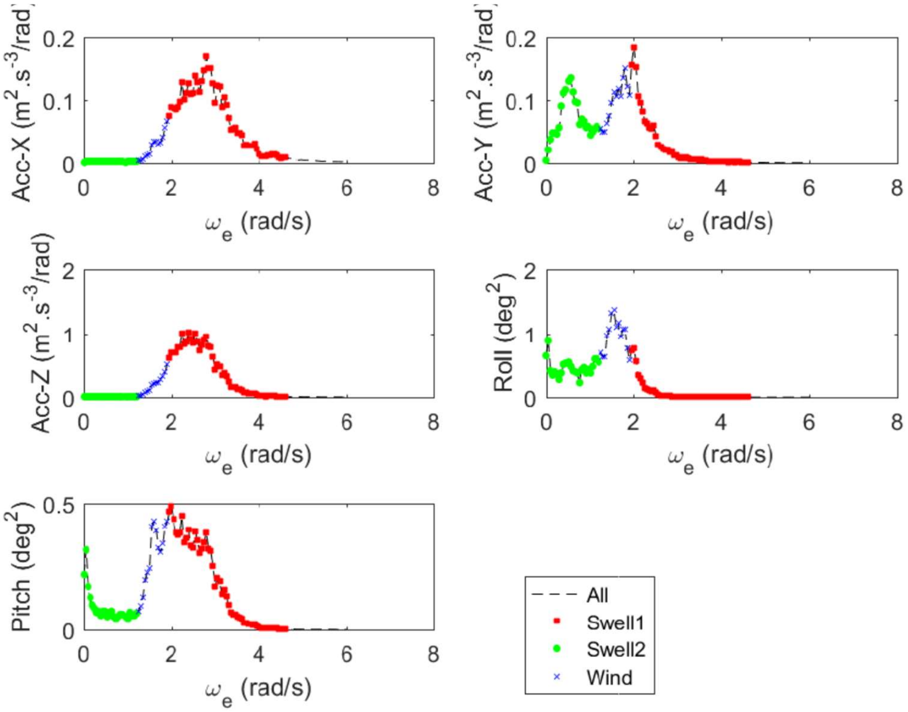


Figure 519: Power spectrum densities of motion response, measured and calculated. Results apply for ship speed 26.3kn, heading 155.3deg, significant wave height 0.81m and peak wave period 5.95s. From left to right, then from top to bottom: longitudinal acceleration, transversal acceleration, vertical acceleration, roll motion, pitch motion. Red: induced by primary swell. Green: induced by secondary swell. Blue: induced by wind sea. Dotted lines: measurements. Solid lines: calculations.

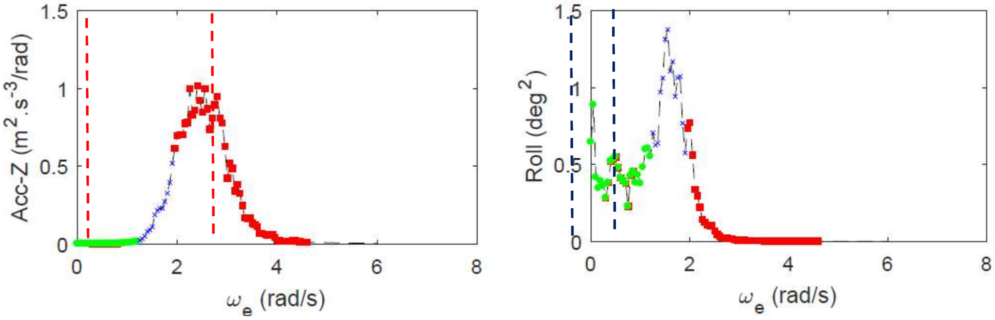


Figure2.20: Power spectrum densities of motion response. Left: vertical acceleration. Right: roll motion. Red: induced by primary swell. Green: induced by secondary swell. Blue: induced by wind sea.

As a result of the comparison between the measured and the simulated data, we observe that some of the hypotheses in the simulation may be questionable:

- the assumption that the JONSWAP wave spectrum formulation is valid for small waves;
- the linear assumption in the numerical (PANSHIP) model;
- the assumption that the CTV input data and applied environmental conditions are reliable:
    - The hull geometry, the loading condition and the trim flap angle are not known exactly and estimated with best knowledge based on general arrangement drawings and onboard stability logbooks.
    - The local weather conditions are not fully known: the Copernicus 027 hindcast model gives a good prediction of the sea and swell waves, however directional spreading, current and wind are missing.

Further validation can be completed through model tests, this is a proven method to collect high quality data for validation.

2.2.5 Model tests for validation of seakeeping tool

From the results obtained so far, we observe that the validation and tuning of the numerical simulations is hampered by many uncertainties, resulting in a mismatch of full-scale measurements and simulations. These uncertainties are related to:

- vessel data
    - hull geometry
    - loading condition

- environmental conditions
    - wave spreading
    - effect of current

- numerical model
    - linearized approach

Therefore, additional scope to perform dedicated model tests has been initiated to generate reliable validation data. These model tests comprise the build of a scale version of a Crew Transfer Vessel and significant physical indoor tank testing. These validation model tests are valuable as they are carried out with known input parameters:

- vessel data
    - hull geometry
    - loading condition

- environmental conditions
    - regular and irregular waves
    - wave spreading

Validation of the numerical (PANSHIP) model by dedicated model tests allows us

- to confirm the validity of the calculated results, indicated by the light blue line in Figure 1;
- to reveal the effect of wave directional spreading;
- to confirm nonlinear effects.

Moreover, model tests will provide data for further improvement of the numerical model. This will be used to update the model and vessel look-up tables when it becomes available.

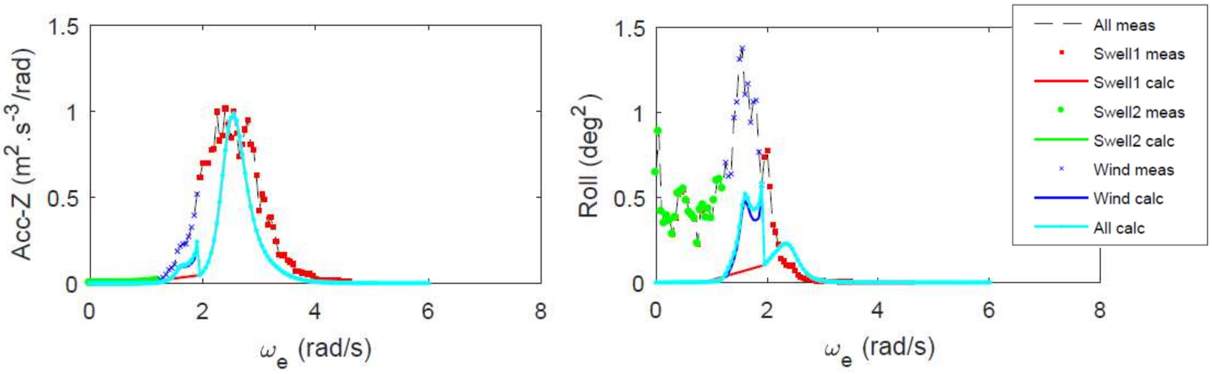


Figure 2.21: Power spectrum densities of motion responses, highlighting calculated vs measured data. Results apply for ship speed 26.3kn, heading 155.3deg, significant wave height 0.81m and peak wave period 5.95s. Left: vertical acceleration. Right: roll motion. The solid light-blue line represents calculated results.

2.2.6 Conclusions and recommendations

The following is concluded from the hydrodynamic analysis in comparison with the onboard measurements:

- The numerical simulations represent stable conditions i.e. constant speed, course and environment. In reality the ship course and wave conditions vary continuously, and stable tracks are of limited duration. This makes a good one to one comparison between simulations and onboard measurements difficult.
- The comparison between the result of the simulations and onboard measurements shows significant differences. On the one hand these can be due to unknown input parameters for the numerical model. On the other hand, these can be due to inaccuracies in the numerical model.
- The results of the numerical simulations are sensitive to the following input parameters:
  - The hull geometry, the loading condition and the trim flap angle are not known exactly and estimated with best knowledge based on general arrangement drawings and onboard stability logbooks.
  - The local weather conditions are not fully known: the Copernicus 027 hindcast model gives a good prediction of the sea and swell waves, however directional spreading, current and wind are missing;
- The linear hydrodynamic assumption might not be fully valid. The onboard measurements show low frequency motions, which are not represented by the linear calculations. Furthermore, slamming is not represented by the linear calculations, while in practice this does result in discomfort for the crew.
- To validate the accuracy of the numerical simulation, model tests are being performed in laboratory conditions as additional scope to further validate the results. In these model tests the input parameters (hull geometry, weight distribution, wave conditions) are known exactly. The model tests will reveal if the differences between the onboard measurements and numerical simulations are due to the input parameters or due to the inaccuracy of the numerical model. If it is known to be the latter, then focus can then be applied to refine the numerical model.
- The seasickness formulation developed in the present research is implemented successfully in the numerical model. As such the numerical simulations allow to predict the discomfort for crew on CTV operations.

3 Human Factors

This section of the report focuses on the work led by The University of Hull under work packages 4 and 5, with support from BMO, SGRE and ODSL. This comprised information gathering – including via an extensive set of sea trials – and the analysis of this data to formulate a model of the impact of vessel motions on human state.

3.1 Literature

In order to devise a valid measurement of seasickness, existing academic seasickness literature was reviewed. Findings from the seasickness literature provided useful background and theoretical frameworks to guide interview protocol and drive the field study variable development. The prevailing theory of motion sickness in the literature is the neural mismatch theory (Reason, 1978) which posits that motion sickness is the resulting state from a discrepancy between a number of systems including the vestibular and ocular systems, and prior cognitive models of motion from memory. Understanding this model allows for a greater understanding of the causes and coping strategies of seasickness, and provided a basis on which to expand reading, and develop variables for seasickness triggers.

Seasickness symptomology was also well documented within the literature and there was found to be a widely agreed upon set of symptoms (Cheung, 2008; Gianaros et al, 2001; Lackner, 2014). The most commonly occurring symptoms can be grouped into four sub-categories: cognitive (including dizziness or light-headedness), temperature (including feeling clammy or sweating), sopite (including fatigue and irritability) and gastrointestinal (including nausea and vomiting)

As well as seasickness symptomology variables, the literature review also provided insight into measurement tools for subjective seasickness data collection. Whilst there were a number of published scales identified for consideration, no scale fully met the requirements of the project and the data collection protocols. The prominent reasons for excluding published scales were either having too many items to be feasibly completed in a short time, or having questions framed to capture data retrospectively rather than current state. It was decided by the UoH research team that the Motion Sickness Assessment Questionnaire (MSAQ) (Gianaros et al, 2001) would be adapted to form the SPOWTT seasickness questionnaire basis, providing the quantitative data required

As well as characterising seasickness, guidance was taken about the effects of motion on sea-seasickness. The key theoretical paper is Reason (1978), which gives underlying ideas of movement only. The key literature for this study uses vertical (z) acceleration and frequency as the two parameters: O'Hanlon et al (1973) shows seasickness increasing with vertical acceleration but a non-linear relationship with the greatest effect around 0.2 Hz; this is also quoted as fundamental by Matsangas (2013) and Calvert (2005) quotes the equation fitted to the results for acceleration. Of course these parameters need to be summarised over the trip for our purposes so Stevens (2002) notes the ISO/British Standard methodology of integrating (square of acceleration) over the dose period. Indeed, these standards suggest weighting the dose by the frequency with a non-linear curve maximized around 0.2 Hz.

However, there is a stream of work (particularly from a team at TNO led by Prof. Bos) extending this. Wertheim et al (1998) say that pitch and roll multiply heave (i.e. a small unimpacting heave will become impactful with pitch or roll); the NATO standard (Brooks et al 2002) uses these figures; Bles et al (1998) gives further explanation of this (and emphasise the figure of 0.2 Hz); further commentary comes from

Bos (2011); Dallinga et al (2002) look at the implications of this and talks about different headings relative to waves and speed and their implications; similar comments apply to McCauley et al 2007. Further to this, Pisula et al (2012) say that all three axes are important. They note that the z-axis depends upon the position in the boat due to the pitch movement (although this is for bigger boats). Similarly, Khalid et al (2010) (includes Bos) explains why this is important and looks at all SIX vessel motions. Following these considerations, this study looked at all dimensions of motion, but looked at the frequency of the motion, which the literature implied was critical. It was feasible only to calculate the cumulative vessel motion with given pre-chosen frequencies. Discussion within the consortium suggested that since BS2631 and the literature identifies 0.16 Hz, this should be the key frequency; other suggestions mooted 0.4 Hz as important; in order to cover a range, a higher frequency, 0.1 Hz, was chosen, plus a lower frequency, 0.6 Hz. The analysis therefore concentrated on four frequencies: $f_1=0.1$ Hz, $f_2=0.16$ Hz, $f_3 = 0.4$ Hz, and $f_4=0.6$ Hz.

3.2 Scoping Study

The first, scoping phase took place in late 2017 and consisted of interviewing OSW industry professionals to gather industry and context specific information to validate and contribute to the pilot study protocols. By talking to industry professionals, it was possible to (1) gain information about the practicalities of collecting field study data, (2) contribute to the pilot study methodology and (3) investigate the subjective experience of transit. The University of Hull research team conducted 14 interviews to address these topics. Findings covered the experience of seasickness (frequency, the effect of mental workload, symptoms, coping strategies, recovery time and environmental triggers. The effects of seasickness covered anxiety, fatigue and readiness to work

The scoping phase also aimed to gather quantitative and qualitative data of past transits from a wide range of sources. This included the proposed task of examining formal documentation of historical incidents. However, following considerable efforts from the SGRE team, it was not possible to find relevant, reliable and quality information from the in-house HSE reporting tool (KRIMA) tool that could be included in this study. We were kindly provided access to seasickness incidence information through the SGRE Grimsby Marine Coordinators who are responsible for keeping a log of all seasickness incidents reported in the field, which gave some indications of frequency. Due to the lack of detail in the log surrounding the causes or consequences of the reported seasickness, there was little to be gained regarding variables to be measured, or practical considerations for data collection. The report however does suggest that an understanding of vessel motion caused by sea state, and the implications for seasickness, would have been a useful tool in the decision to sail (or not) on these days.

3.3 Data Collection Plan

It was decided to collect a number of subjective factors using a bespoke App, to be run on technicians' iPads that are routinely used to manage work tasks. This availability allows for an efficient method of data collection which would result in minimal intrusion into the technicians' normal working day. Data was collected at six time-points

- T1 - Prior to transit
- T2 – During transit to turbine (around halfway)
- T3 – On the turbine, prior to work
- T4 – On vessel, prior to transit to dock
- T5 – During transit to dock
- T6 – "End of workday" prior to disembarking

In addition, if seasickness was felt to be acute, a "T99" report could be filled in at any time.

In the pilot study, physiological data was also collected. This eventually did not form part of the final study, since insufficient evidence could be collected to show that movements of technicians' bodies were sufficiently different from the movements of the vessels, and secondly because it inhibited technicians from collaborating with the study. This is therefore not discussed further here. It should also be noted that at the project inception, consideration was given to investigation of the impact of individuals' fitness on their predisposition to sea sickness; this could not be implemented for operational reasons.

The vessel and environment data collection was carried out by BMO using the Vessel Motion Monitoring System (VMMS) as discussed in section 2.1. The main data collected for this purpose were accelerations in all dimensions. In addition to these motions, an environmental kit was installed on a select number of vessels. This additional kit recorded oxygen levels, temperature and sound pressure levels (noise) in the cabin to see if these had any effects on the subjective states of the subjects.

3.4 Phases

The project started with a phase 1a pilot data collection running from June to July 2018. Six SGRE technicians, working on the LID site, took part in this phase of the project. Physiological, psychological (subjective), and vessel motion data was collected using the methodology and equipment outlined above. Overall, the sample size available at the LID site was much smaller than originally thought, due to various organisational factors including those caused by site ownership changes that resulted in a number of resource challenges. Nevertheless, and despite lower than expected participation levels, the exercise indicated that the chosen methods could provide important guidance for the main data-collection study.

This was followed by a Phase 1b data collection and a period of reflection on what we had learnt. It was clear that there were some issues with the performance of the data-collection App, and this was revised for what was hoped to be a much bigger Phase 2 data-collection period.

3.5 Data

In the event, the total set of subjective data was 360 person days (i.e. trips outbound and inbound together), with 175 person-days for Phase 1 added to 185 person-days of data for Phase 2. There were a number of records for which a vessel could not be defined.

The dates for all trips, where there was usable app data on which vessel was used, were then passed to BMO. This consisted of 82 days (outbound and inbound, that is, 82 * 2 = 164 separate transits) for Phase 1 and a further 82 days for Phase 2 (these are the same figures, which is coincidental although illustrative of the lack of success in widening the data-collection). BMO then provided the characteristics of those trips (inward and outbound) where they existed, as per the set of characteristics following:

- date and time of the trip;
- vessel;
- start time, stop time and duration;
- noise measures: an average figure (equivalent continuous SPL), a figure increasing with duration (equivalent 1 hour), and an effective maximum (99th percentile);
- temperature measures (rms, mean, median, min, max and range);
- Root-mean-square value of the acceleration of the sensor in each axis;
- Roll, pitch and yaw rms;

- The Power Spectral Density ("power" below) of the acceleration signal on each of the three axes at each of the 4 frequencies of interest: f_1=0.1 Hz, f_2=0.16 Hz, f_3 = 0.4 Hz, f_4=0.6 Hz; this is defined by BMO as shown in Appendix 1;
- The Energy Spectral Density (esd) (i.e. power * duration) over the entire transit of the acceleration signal on each of the three axes at each of the 4 frequencies of interest: f_1=0.1 Hz, f_2=0.16 Hz, f_3 = 0.4 Hz, f_4=0.6 Hz.

It was known that a small sample of trips did not have data, and there were a few trips in the final part of Phase 2 that were taken upon a vessel that was not fitted with BMO kit, but for most trips there was extant data.

The data described in the current report represents the output of extensive engagement. However, despite considerable efforts to maximise data quality and quantity it should be noted that the final data set is substantially smaller than anticipated for a variety of reasons.

3.6 Analysis of Subjective Data

Seasickness was defined as comprising five related symptoms: nausea, dizziness, sweatiness (temperature disturbances), irritability and headaches. There were very few reports of seasickness symptoms, with headaches being the most frequently reported. All symptoms (except sweatiness) were at their worst at T2, mid-point of the outbound journey. T3 is typically reported once safely located on the turbine, so this may explain why this is not cumulatively worse than T2, as some recovery will have taken place. With regards to sweatiness, the height of this symptom at T4 is consistent with subjective reports, that the participants have often just climbed down from the turbine, often wearing immersion suits and sometimes returning to a warm vessel that has been in direct sunlight. This is likely to be more of a response to the wider environmental context, rather than as an element of the cluster of seasickness symptoms. It should be noted that these mean differences are relatively small.

In addition to measuring current seasickness symptoms, previous reports have also discussed a state best described as 'pre-seasickness' i.e. the experience of a developing state which, if actively controlled, can be stemmed. Both mental and physical management strategies were reported including exerting additional mental effort to maintain control, and physical strategies such as lying down. These seasickness management strategies were measured at T2 & T5 to assess in-transit state. Consistent with the prevalence of seasickness symptoms, the results show only infrequent reports of mental and physical management strategies. Of course, the mental and physical management of seasickness is closely related to the symptoms. The correlation between management of seasickness and the symptoms were moderate and significant at the 99.9% level, except for irritability on the return journey.

The impact of transit on technicians is wider than just seasickness, fatigue has been highlighted as an important area for investigation, as this has clear implications for safety behaviours and the increased risk of incidents. We again showed relatively low levels of reported fatigue. However, again fatigue was lower, on average, at the end of each journey than the start, suggesting that, in general, the transit experience was not inherently fatiguing for those journeys we measured in the SPOWTT project, most of which were not problematic or borderline. Although, this may be partly also due to two factors of (1) time-of-day effects and (2) technicians sleeping on the journey. The impact of more challenging transits on fatigue is an interesting question for a further research project as these transits may result in increased fatigue across T1 to T3 and T4 to T6.

In addition to measures of subjective state, technician evaluations of (1) readiness to work (this was asked subjectively to act as a proxy for an objective measure of "fitness to work", which the project could not establish) (2) planned tasks and (3) required recovery were incorporated into T1 and T3 to act as a proxy for objective measures of work. As would be expected from the nature of the items, these were distributed differently to the subjective state measures, with readiness to work being positively skewed and task evaluations being more normally distributed. Within individuals these scores were significantly correlated suggesting that recovery time taken was relatively consistent with evaluations of safety requirements. To consider this further, a difference score was calculated, of which 64% of responses were 0, indicating no difference between the amount of time recovery taken and how long to feel safe, but half of the remainder reported a negative score (range -1min to -20mins) suggesting that technicians sometimes begin work before they feel they are safe to do so; this is an important finding and should be considered in its effect on the safety culture on site – to ensure technicians do not begin work when they feel it is unsafe. Work evaluation measures were also incorporated into T4, to provide an evaluation of work demands and work performance. It should be noted however that further research would have to be conducted to have more confidence in the above indications on recovery time.

Very few "T99" reports were made, but there was some results of symptom order and attribution worth noting.

Demographic data for individuals was available covering personality data, age, gender, height, weight, years in current role, marine experience (no/some/experienced) and fitness. At this stage of the analysis we did not use this data, because (a) there was insufficient individual participants for findings to be robust, and (b) these variables are not under the control of the schedulers. In particular for (a), because we are not doing a repeated measures analysis, the heterogeneity in response rates (i.e. some technicians making one or two submissions and some making many) would make the results particularly unreliable, and likely to result in an over estimation of the importance of personal factors.

3.7 Combined Analysis

The central aim of the study was to explore and understand the relationship between vessel motion and person state. As outlined above, the volume and quality of data yielded from the field study limited the range of analysis that could be undertaken and also necessitated caveats around the robustness of the findings. However, the full set of results (available on request) reveal some interesting findings, consistent with (and extending) the current literature.

The app responses, as described above, were combined into one SPSS file with the transit vessel motion data for the particular trips for which there were app responses, using the headings outlined earlier.

It should be noted at this point that, in order to utilise the limited amount of data, each app-trip is being treated as a separate piece of data, ignoring for now the fact that (a) multiple trips are made by the same participant and (b) multiple participants are on the same transit. It had been hoped to gain sufficient data to perform repeated-measures analyses but the number of participants is simply too small and unbalanced for this.

We also looked again at the environmental data. Out of 360 person-days we only have 140 temperature/sound readings outbound and 122 inbound: looking at these variables, we found possible significance in the mean temperature (and temperature had featured in the T2 reports) so this item of data was maintained but we did not use the remainder in the analysis.

We then used sets of hierarchical multiple regressions to explore the factors which predict the range of seasickness symptoms. The results came from using the frequency-weighted data, and specifically the “energy” or “esd” figures: using a linear regression of “Power” and including “duration” would treat duration as a linear variable, whereas its effect would be expected to be multiplicative; multiplying “power” variables by duration gives the energy variables.

Looking at time T2, during the journey, initial impressions suggest that the condition of the technician before sailing is important, in particular the level of sleepiness they feel. However, also important is the movement of the vessel. Nausea and physical management of symptoms appear to be most sensitive to vessel motion, followed by dizziness and active mental management of symptoms, with x, y and z accelerations all important.

Time T3 is the key observation for the purpose of the SPOWTT study, as it is at this point that the technicians are about to start work on the turbine. At this point in time, particular *symptoms* of seasickness seem to be coming from the vessel motion: nausea, dizziness and headaches, driven directly from all three directions of motion at various frequencies but particularly the y direction (especially 0.16 Hz). Subjective readiness to work seems to be more the prior state of the technician: the previous night’s sleep in particular, giving an immediate feeling of unreadiness to work. However, vessel motion does also influence mental and physical fitness to work (specifically Y motion at 0.16 hz). Feelings of fatigue at time T3 seem to be largely from condition prior to travelling.

Time T4 represents getting onto the vessel at the end of the work on the turbine. We wish to consider how the day has gone, that is their ratings of: engagement, efficiency and effectiveness, and their current mental, physical and sleepiness fatigue state. Here, for evaluation of work performance (“how engaged/effective/efficient were you?”), clearly the journey out has quite an effect on the ability of technician to engage and be efficient, particularly X movements (and Z but not Y movements): perhaps the X movements have a longer-lasting effect. With regards to fatigue, by the time T4 has come, tiredness is due to the demands of the work as well as the initial state of the technician.

Similar to time T2, time T5 represents a point roughly halfway back from the turbine. There were few strong relationships here, but what relationships there are mostly come from the state of the technician at time T4 (leaving the turbine) but also some effect still from T1, and anxiety about the sail home. This is notably different from the position at T2 on the way out. For both T2 and T5, it should be noted that the vessel-motion variables entered are for the whole journey, half of which is after T2/T5, so these results should be treated with some caution.

Time T6 represents the arrival back at base. Results here show a complex set of effects, with symptoms caused by both the state of the technician on beginning the journey back, and the vessel motions. All three dimensions – x, y and z, play a role. Irritability, mental fatigue and sleepiness are all importantly affected– these are important as the technician is about to drive home.

All of these analyses highlight the complexity of the impact of transit on work and wellbeing. It is clear that a full understanding of the development of seasickness and its effects requires a multidimensional model of seasickness and a multidimensional model of fatigue. Also, a frequency weighted measure of motion parameters is important for understanding the relationship between motion and the range of dependent variables.

3.8 Equation Modelling: Representing Sea sickness

An immediate need from the above results is to populate a model for the SPOWTT system. In other words, we need to establish the basis for a function

f(vessel motions) = seasickness

In order to investigate this, we need to establish first the meaning of "seasickness" in this equation since there are many dependent variables.

We have five different symptoms of seasickness, some of which seem to be more important and also more influenced by the journey: We have an "overall seasickness" variable at time T3, measures of mentally/physically managing state to prevent seasickness at time T2 which are highly correlated with the symptoms, and at time T3, three fatigue variables and three variables about readiness to work. This last set of six variables according to the results above appeared to be more related to initial state of the technician than to the journey. The analysis below will therefore concentrate on seasickness itself, but will also look at its relationship with the readiness to work of the technicians.

We need therefore to establish a single variable for "seasickness". There are five symptom variables at time T3 plus an overall evaluation of "seasickness". These variables are highly inter-correlated and factor analysis shows one component in the data that has the following component matrix:

$$\begin{aligned}\text{SS component score} = \; & 0.908 * \text{nauseous3} + 0.918 * \text{dizzy3} + \\ & 0.663 * \text{sweaty3} + 0.623 * \text{irritable3} + \\ & 0.793 * \text{headachy3} + 0.884 * \text{SSoverall3}\end{aligned} \tag{1}$$

Preliminary item-response theory analysis showed that symptom variables were good variables (i.e. all have good variance) but as seen by the component factor, sweatiness and irritability were less central. Therefore for this analysis, we will use the component variable as defined above. Further analysis could consider whether using a reduced variable set makes a significant difference to the T3 results and could look at the different symptoms from time T4-T6.

This Seasickness Component variable had 241 valid responses and 119 missing values. Of those 241, 115 (47.7%) had a value of 4.79, being the value obtained when no seasickness was reported. The other 52.3% ranged in value from 5.41 to 27.98, with a mean of 10.31.

It should be noted that SPOWTT data is by definition self-selected on journeys that can be sailed. If weather is too bad, boats do not sail, or turn back, and no data is obtained for SPOWTT. Considerations based on this data of when travelling conditions are "too bad" has to remember that these conclusions will go beyond the envelope of this data.

There are a number of other variables which indicate how ready to work the technician is, or feelings at time T4 as to how their day went. Six variables were particularly significant here. The Seasickness Component variable above appeared to be a good predictor of all of these, being very significantly correlated. This suggests that this variable is useful for predicting both the effects of the journey and the subsequent effect on fitness to work, but the moderate r values suggest that other factors also influence this state.

3.9 Equation Modelling: Relating to vessel motion

A linear regression of vessel movements against the seasickness variable above suggests that the larger the problematic parameters of vessel motion, the higher the *SSComponent*. But a score of 43.1 clearly does not represent the maximum possible vessel movement. Secondly, the vessel movements should give rise to a seasickness prediction that increases asymptotically up to a maximum (say, 1). Logistic regression is the idea, but this is explicitly analysing dichotomous variables and our seasickness is a continuous variable.

Therefore we firstly used a normalised (0-1) version of our seasickness variable, call it SS. For the purposes of this analysis we have taken this to represent an arbitrary 90% level of seasickness; it is also inconvenient to allow the score to fall to zero so we are assuming that the minimum score represents a very low level of seasickness. This gives the following (where a minimum component score of 4.79 which gives a value of SS=0.02 and a maximum component score of 43.1 gives a value of SS=0.9):

$$SS = (\text{SS component score} - 4) / 43.4 \quad (2)$$

Then rather than attempt to interpret output from a logistic regression we will take the idea of a logistic function and model it explicitly. Thus we use in the regression not SS but a logistic function of SS, namely

$$\text{logitSS} = \ln(SS/(1-SS)) \quad (3)$$

We regress vessel movements against this variable.
Predictions of logitSS will then be converted back to predictions of SS by the reverse formula to give a prediction a 0 to 1 value of seasickness.

$$\text{Seasickness prediction} = 1 - 1/(\exp(\text{logitSS})+1) \quad (4)$$

More data would allow more confidence in determining the shape of the logistic curve, but it is felt that the limited data, only 241 data points of which 115 were at the minimum value of seasickness, leaving only 126 points showing any variability, would not make these results robust.

But by the above means we can carry out a full multiple regression against an unbounded variable that behaves the way we wish, and convert this variable to our understandable SS value.

It is clear that:

- It is only the outbound journey that affects people's ability to work on the turbine, the primary question of interest to SPOWTT;
- The psychological effects demonstrated on the outbound and inbound journeys are clearly quite different and combining the datasets would muddle these together.

Our analysis therefore considered ONLY the outbound journey.

The data from BMO was uploaded, then a regression carried out between the logit function above and independent variables including vessel motions, duration and drop-off order. Vessel motions included power and energy variables, and also the square-root of the PSD- and ESD-values (see equation 1 of Joseph & Griffin 2008 for an example).

In the event, the clearest model used the "power" variables with

$$\text{Prediction of logitSS} = -3.499 + 18.876 * \text{accX\_power\_f\_3} + 37.552 * \text{accY\_power\_f\_2} + 11.369 * \text{accZ\_power\_f\_3} + 281.337 * \text{accZ\_power\_f\_2} \quad (5)$$

If this equation had been used to predict seasickness on the trips for which we have data, remembering that our data is only for trips that were calm enough to sail, for 99.5% of the trips it would give a prediction below 0.4.

3.10 Conclusions and further analysis

Despite considerable efforts to maximise data quantity and quality, the final data set is substantially smaller than anticipated in the proposal for work. This means that results are much more tentative, and the proper "repeated measures" statistical analysis that was planned would not be reliable or appropriate. A second caveat is that this is all self-selecting data in the sense that, if weather was too bad, vessels did not sail, so we do not have any data in extreme conditions. Thirdly, there was insufficient time to subject the "equation" (5) to rigorous testing for robustness.

The results given above, and more completely in a standalone report, relate to the different symptoms of seasickness and their important correlations with both motion and the initial state of the technician.

A single parameter representing seasickness has been established for use in the equation, which appears to be a good predictor of readiness to work. The immediate task of supplying a model for seasickness which comes out of the data has been satisfied, with an equation which fits the current data-set well.

The work done so far has laid the foundation for more research. In particular, areas likely to be fruitful include further study of the nature of seasickness and different symptoms; study of technician states before boarding; objective measures of cognitive performance on arriving on the turbine; the best way to characterise the vessel-motions in an equation such as the above; the meaning of different values of equation (5); and considerable work on the uncertainty in the overall predictions and relate this to the other uncertainties, such as the weather forecast and the uncertainty effect on vessel motions.

4 Control Measures

This section of the report focuses on the work by SGRE and MARIN, under project work package 6. The general objective of WP6 was "to identify and test control measures that can reduce in a measurable way the negative impact of the transit on technicians and produce recommendations for how these could be integrated into operating procedures."

4.1 Recommendations to the industry

This work package involved the investigation and forming of recommendations around control strategies that can be applied when sailing by CTV. As well as the development and testing of a bespoke onboard advisory tool, the project also collected information on control strategies and other recommendations around the causes and effects of seasickness, and how to control and reduce risks to the personnel offshore. These are outlined below:

1. It has been difficult to ascertain and research the precise typical existing levels of seasickness due to the variety of incident reporting mechanisms used and a realisation that minor symptoms of seasickness seldom, if ever, get reported in the incident reporting systems. Seasickness has a number of related symptoms, in particular nausea, dizziness, sweatiness (temperature disturbances), irritability and headaches. All of these symptoms are important, as they affect the wellbeing of the technicians as well as his/her effectiveness on the turbine. This is supported by the pattern of responses gathered from participating technicians. Seasickness is a complex issue which is relevant for both technicians and the industry as a whole. Anecdotal data shows that seasickness is vastly under reported. Therefore, **the complexity and early symptoms of seasickness should be communicated, and reporting mechanisms established, once robust data has been collected, this can assist in early mitigation strategies**. On a more strategic level, an understanding of levels of seasickness can support the development of industry-related wellness programs.

2. The potential impact of transit on technicians is wider than just seasickness, this research has also implicated detrimental effects the transit and the prior state of the technician potentially have on fatigue and fitness to work levels. Fatigue, in particular, has been identified as a significant contributory factor in accidents/ incidents and, therefore, **strategies to account for recovery times, fatigue and sleepiness scales could be considered by sites and industry**. As an example, there are a number of sleepiness and fatigue tools being evaluated including the HSE Fatigue and Risk Index Tool and the Epworth Sleepiness Scale.

3. There is some evidence to suggest that lack of any recovery time following a marine transit potentially has an impact in that around 20% of those who responded to the survey, based on a relatively small sample size, felt they did not feel as safe as they should do when starting operations. **Further consideration of how to ensure sufficient recovery time should be made.** As survey respondent levels were lower than expected this should be a topic of further research.

4. In addition to above points on 'readiness to work' - when reaching the wind turbine following a marine transit - it appears that another significant issue according to the technician's feedback was weather monitoring and the fear of deterioration during the day. **Concern over developing weather conditions further increases the state of un-readiness and potentially requires further research**.

5. When transiting from the wind farm to port or harbour, technician responses indicate predisposition to irritability, mental fatigue and sleepiness. This could be a direct response to the cumulative effect of the activities undertaken or it could be associated with transits with a higher

degree of X-axis movement on both outward and incoming journeys**. Some means to reduce x-axis motions would be beneficial, as collected data implies that they may have a longer-lasting effect**.

4.2 Onboard seasickness tool

MARIN's focus in regard to 'control measures' was on the design of an onboard tool to inform the captain/skipper about the seasickness index such that he or she can take this into account in the operational choices.

Before departure, the onshore tool (chapter 5) determines the MSI (Motion Sickness Indicator) based on the environmental forecast. Still there are uncertainties in this, e.g. in the weather forecast and the motion response of the vessel.

As soon as the vessel has left the port the actual motions of the vessel can be measured. By using those motion measurements some of the uncertainties can be eliminated and the actual motions can be used to calculate the actual MSI. Based on this the captain can be informed on the present condition of the MSI. In addition, a further step forecasts the MSI at destination or e.g. an hour in advance.

If the MSI at destination is informed to the captain/skipper it is expected that the captain will develop an understanding of what MSI is limiting for a certain population. It would be of even greater benefit if the typical limiting MSI of a certain population was known, such that the (inexperienced) captain/skipper could also be informed actively if this MSI is expected to be exceeded on arrival at the destination.

Each population has its own limiting conditions. To learn the typical comfort limits of offshore wind farm technicians the feedback from these technicians is required. Therefore, the installed onboard tool includes a customer satisfaction survey box. Pressing the emoticon is anonymous and a minor effort.

4.2.1 Development

The hardware consists of a GPS, CMS, and MRU measuring with a frequency of 100Hz.Output is written every 30 seconds.

The software is mainly written in Python, with some minimal HTML+CSS+JS for the visualization of an SVG graph. The data processing module monitors a given directory for data files produced by the data acquisition system, and uses the input for calculations. The log and results are stored and the result is send to the visualization process, displaying the MSI to the captain.

The ISO-MSI equation is used based on a time trace of the vertical acceleration.

4.2.2 Installation

The onboard seasickness tool was installed on one of the vessels within the project during February 2020. First the system shows the captain the current MSI and the MSI in 1 hours' time (**Error! Reference source not found.**). This is based on the measured vessel motions only. Second the crew feedback is measured using the customer satisfaction survey box (**Error! Reference source not found.**). In further research this will be used to define limiting conditions. A questionnaire was filled in by the captains after using the tool, to see how the tool was received.

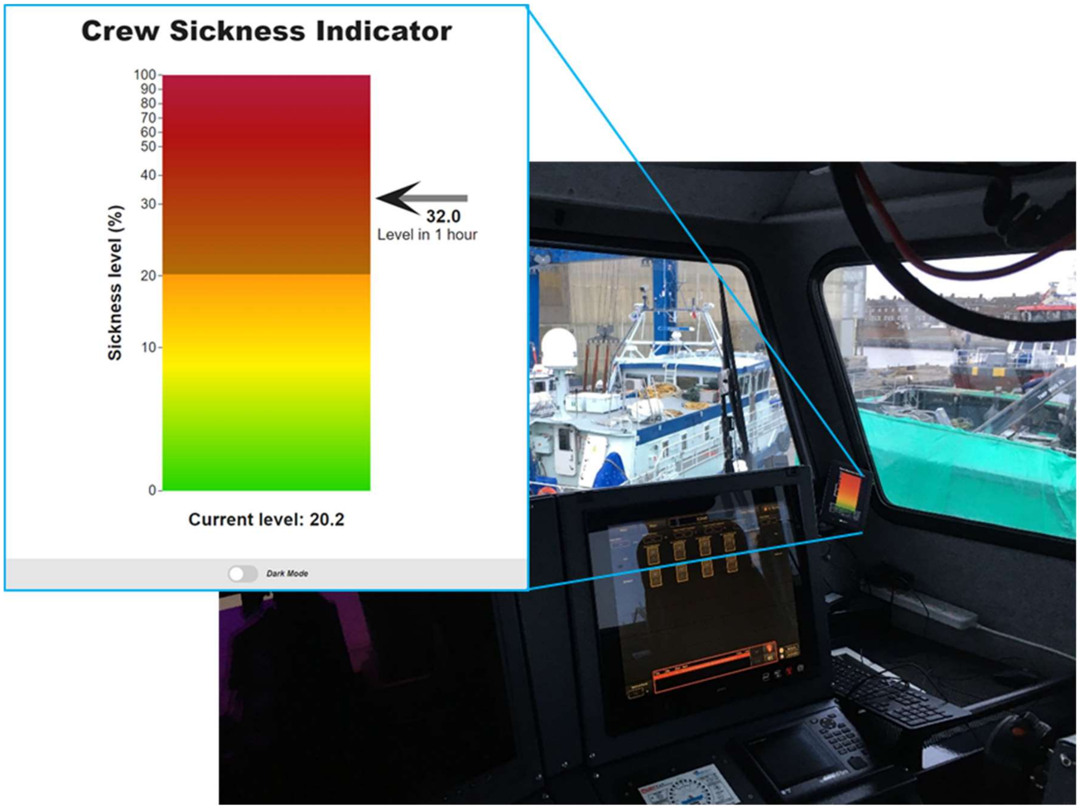


Figure 6: MSI indicator installed onboard a CTV bridge

Figure 7: Satisfaction survey box onboard the CTV.

4.2.3 Outlook

Based on the MSI value and forecast, the captain could take actions to reduce the MSI on arrival. The most likely actions that a captain could take are 1) the change of route or 2) the change of speed.

Option 1, changing the route, can be helpful because the wave conditions can be location dependent and sailing in a more protected area could be beneficial. Furthermore, the heading of the vessel with respect to the wave has a large influence on the vessel motions. However, the possibilities to change the route are generally limited by sandbanks, other traffic and the travel time to destination.
Option 2, changing the vessel speed, influences the motion behaviour of the vessel and possible wave impacts on the vessel. It is possible to change the speed within limits. The upper limit is defined by the installed power. The lower limit can be defined by the vessel's journey planning or achieving an acceptable travel time to the destination.

Error! Reference source not found. shows the effect of vessel speed and course on the MSI calculated according to ISO for a CTV. From this figure the following observations can be made:

- The calculated MSI is largest when sailing into the waves at a high speed
- Reducing the speed when sailing into the waves has a beneficial effect on the MSI
- The calculated MSI is small when sailing with the waves and almost independent on the speed

Changing the course influences the MSI. It depends on the original wave heading if this is beneficial or not for the calculated MSI.

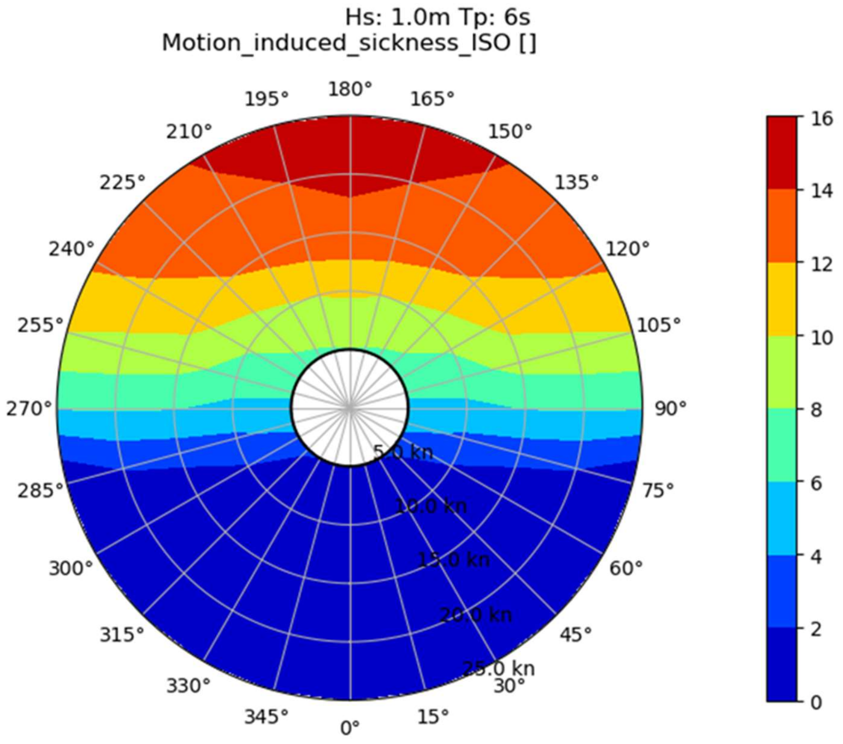


Figure 8: Effect of speed and wave direction on the MSI for a CTV within the SPOWTT project.

4.3 Other control measures

The project team collected feedback from individuals at sites throughout the sea trial phases, regarding their coping strategies for seasickness. Many of these are reflected in the literature, as noted below. The Health Offshore - Manual for health promotion for the offshore wind industry (2019), mentions several recommendations and coping strategies to deal with seasickness:

- The stomach should not be too full or too empty during the transfer. Before departure and on longer journeys it is advisable to eat something in between (e.g. fruit); [reinforced by project feedback]
- No fatty or sweet food should be eaten before and during the trip, instead foods rich in carbohydrates (e.g. bread) should be eaten; [reinforced by project feedback]
- Coffee or juices containing acid should not be drunk before and during the journey as these drinks can irritate the stomach;
- Chewing a ginger root can alleviate feelings of nausea;
- By fixing the horizon or lying on the back with the head raised and their eyes closed; the body can better balance the swaying of the ship; [reinforced by project feedback]
- The avoidance of histamine-containing foods (salami, tuna) is helpful because histamines can promote nausea and vomiting;
- Using drugs against seasickness can lead to fatigue and thus limit the ability to drive and work after ingestion. This represents a safety risk. Therefore, the use of drugs (including over-the-counter preparations) may only take place after consultation with the responsible physician and with simultaneous sick leave. [reinforced by project feedback]

5 Decision Support Tools

This section of the report links to the activities undertaken in work package 7, lead by TNO and SMC, to take the model developed under WP5 and implement it into tools for use by industry.

This work package focused on the longer-term decisions which influence the vessel motions – and therefore health impacts – which technicians are exposed to. While mitigation measures are possible on-board, including slowing down or re-routing the vessel, these can have an impact on the effectiveness of work, and therefore the profitability of the wind farm, on that day alone. It is always preferable to predict and account for such issues at an earlier stage, when feasible. The key decision steps available before the technicians go to sea (working backwards in time) are:

1. Checking the weather forecast on the morning of the voyage, determining whether the voyage should go ahead either: as planned; with adjustments; or not at all. Wind farms do not typically cancel voyages at this point, unless the conditions are poor or are deteriorating. If technicians are available, they may go to sea and consider cancelling later if transfers are not possible or severe motion sickness symptoms occur. As expert mariners and marine coordinators, SMC focused on supporting this decision.
2. Transfer planning the previous day. A choice is made about whether a voyage is planned at all. Thereafter, choices of routes and timings of turbine visits are instrumental in determining the motions the technicians are exposed to, the amount of work done, and ultimately the profitability of the wind farm and its operator. TNO's expertise is on supporting this decision, and so their work in SPOWTT was focused here.
3. Selection of the contracted vessel. A vessel's behaviour in different sea states determines the health of the technicians and the weather conditions in which work can be done. Combined with its reliability, rental cost and fuel efficiency, this determines long-term: how much work can be done on the wind farm; its profitability; and the effectiveness of later planning and seasickness mitigation measures. SMC used their expertise to focus on supporting this decision.

Central to all decision-making is simulation of the future: a method of predicting the outcomes of a given decision and weighing its merits and downsides against alternatives. For short-timescale decisions, with few options, human experience is difficult to better. However, when decisions have longer-term resonances, and the possible options are numerous, computers often provide a faster, more accurate way of calculating the future and sifting through the options. Humans, on the other hand, usually develop heuristics: rules of thumb that work reasonably well most of the time.

In offshore wind farms, a good example of a heuristic in widespread use would be the concept of a 'weather day': if the significant wave height is forecast to be above a certain vessel-relevant height, for instance 1.5m, then work on the wind farm is not planned. This can result in wasted trips, or lost opportunities. TNO's "ECN Despatch" software aims to make the choice of transfer plan for the next day faster, more effective, and more focused on the business objectives of the operating company. By using a discrete event simulator to evaluate the outcome of a given plan, the timings of all actions and therefore Key Performance Indicators (KPIs) can be established: such as number of work orders completed, time and cost of technicians, cost of vessels, and wind farm energy output or even income.

The site planners can then use this information to try different plans quickly, discuss the trade-offs with site management and team leaders, and make a decision with confidence. Several key improvements to the software were made in this project:

1. The process of daily maintenance planning was understood in detail by working on several wind farms side-by-side with the planners.
2. A new user interface was designed around that process, to enable site planners to test the software and feedback the value and improvements they see.
3. Vessel motions and seasickness limitations were introduced, resulting in variable speed vessels and more accurate conformity of the simulation with human transit limitations.

5.1 Functionality

Through interviews at an offshore wind farm the process diagram shown below in Figure 5.1 was created. The red dashed box highlights the decision processes which the tool supports. This process is considered representative of all offshore wind farms.

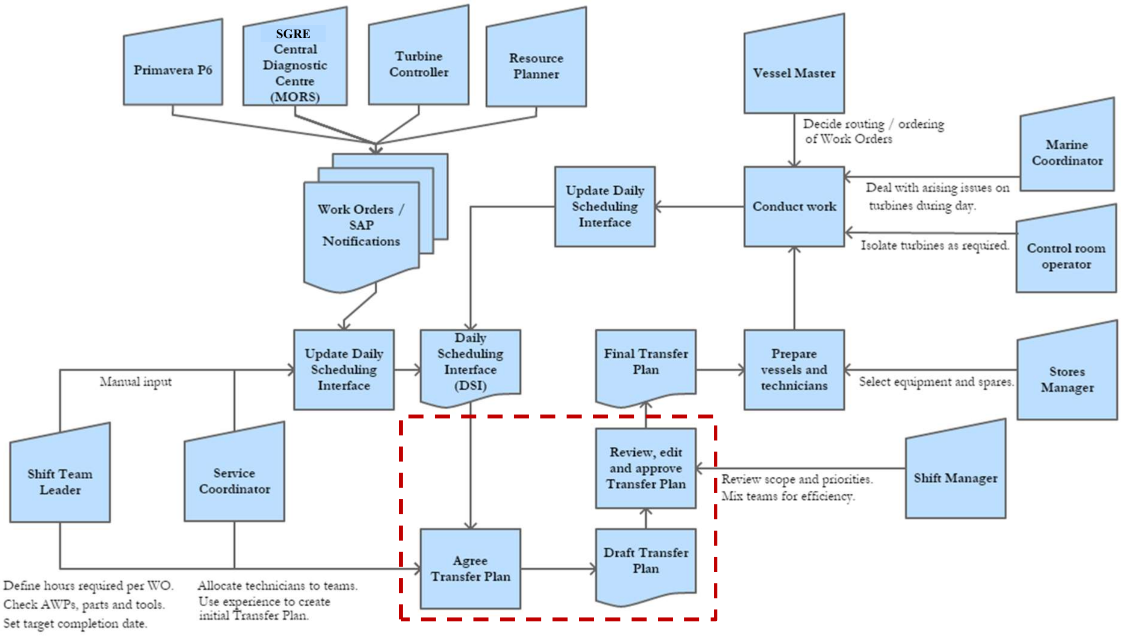
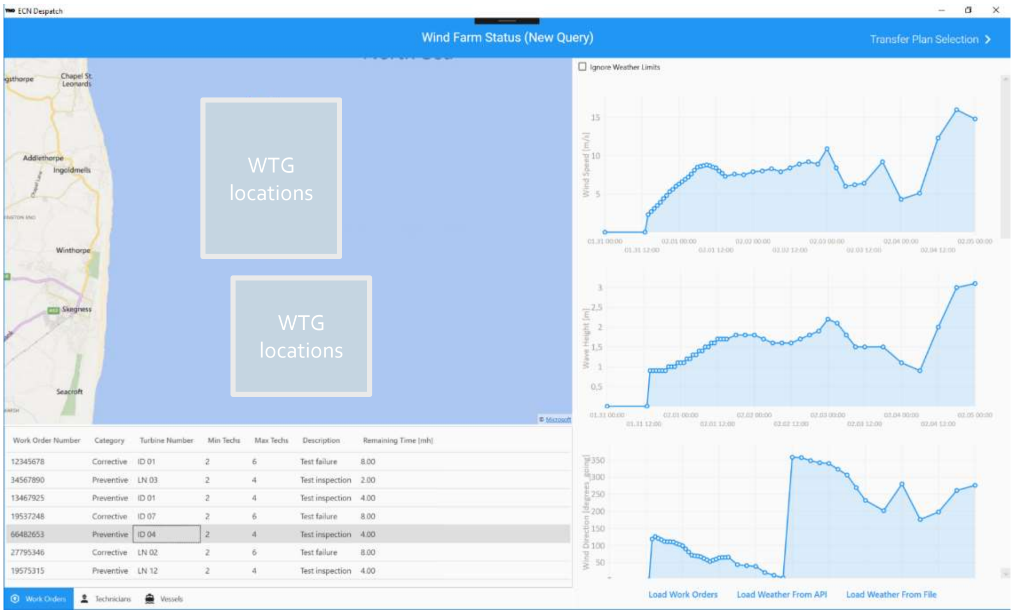


Figure 5.1 – Process diagram

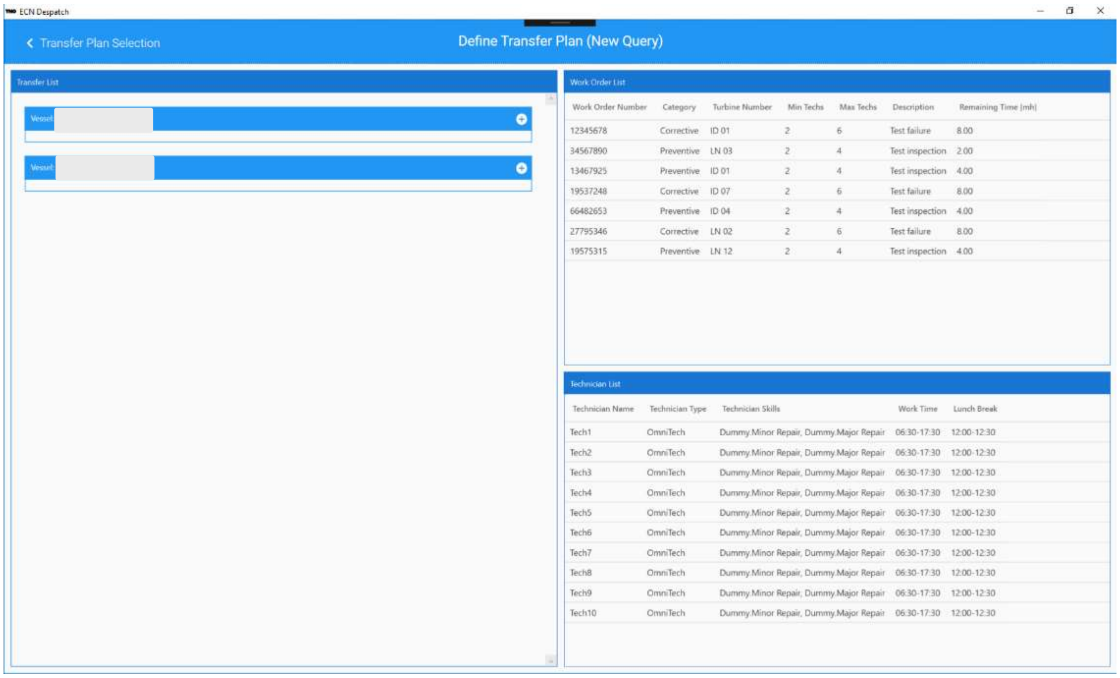
A user interface was created from this, to enable the wind farm site planners to test the functionality of the tool while doing their daily job. Initially, the static information about the wind farm (turbines, vessels, technicians) is provided by the wind farm owner or operator and stored in a database that runs in the background of ECN Despatch. These are visualised, as shown in Figure 5.2, when opening the software. The user can load in a simple Excel spreadsheet with the work orders, and either load a text file with the weather data, or automatically download the latest forecast from StormGlass (a free service) or StormGeo (if access has been paid for).



Work Order Number	Category	Turbine Number	Min Techs	Max Techs	Description	Remaining Time [mh]
12345678	Corrective	ID 01	2	6	Test failure	8.00
34567890	Preventive	LN 03	2	4	Test inspection	2.00
13467925	Preventive	ID 01	2	4	Test inspection	4.00
19537248	Corrective	ID 07	2	6	Test failure	8.00
66482653	Preventive	ID 04	2	4	Test inspection	4.00
27795346	Corrective	LN 02	2	6	Test failure	8.00
19575315	Preventive	LN 12	2	4	Test inspection	4.00

Figure 5.2 – Static information about windfarm

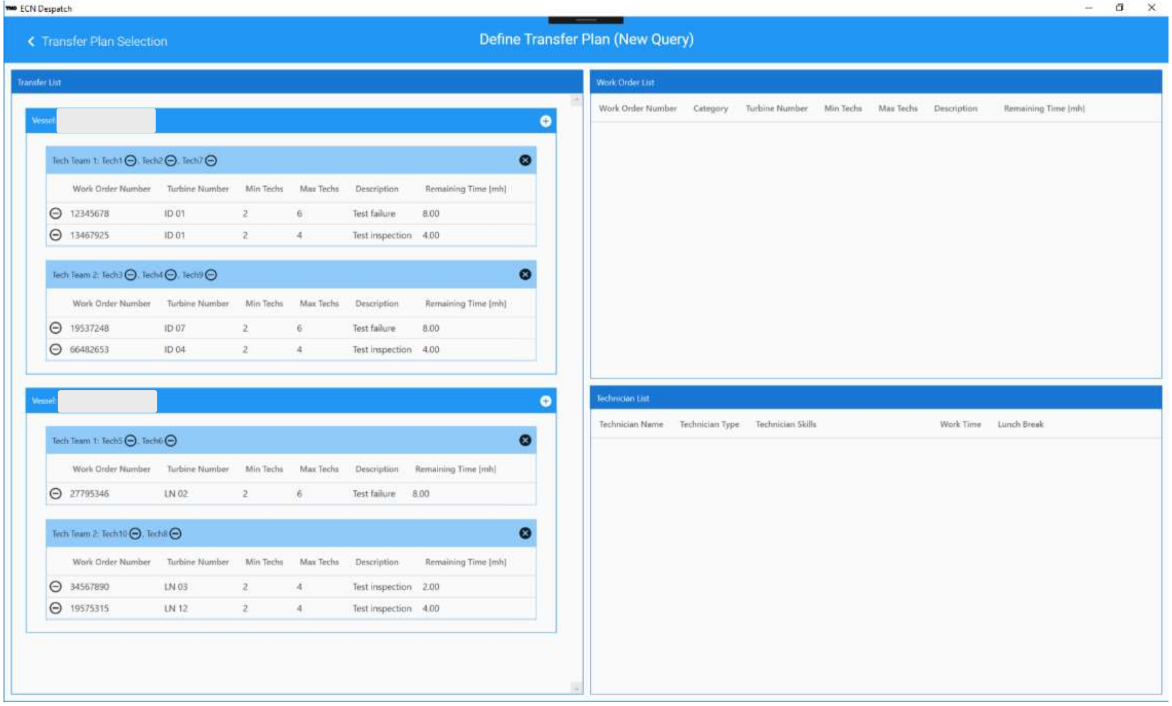
The Transfer Plan is then created by adding technician teams to vessels and giving them available work orders. Before and after images are shown in the below figures, illustrating this process. Various rule sets for business processes regarding the acceptable combinations of technicians and work orders are built in.



Work Order Number	Category	Turbine Number	Min Techs	Max Techs	Description	Remaining Time [mh]
12345678	Corrective	ID 01	2	6	Test failure	8.00
34567890	Preventive	LN 03	2	4	Test inspection	2.00
13467925	Preventive	ID 01	2	4	Test inspection	4.00
19537248	Corrective	ID 07	2	6	Test failure	8.00
66482653	Preventive	ID 04	2	4	Test inspection	4.00
27795346	Corrective	LN 02	2	6	Test failure	8.00
19575315	Preventive	LN 12	2	4	Test inspection	4.00

Technician Name	Technician Type	Technician Skills	Work Time	Lunch Break
Tech1	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech2	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech3	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech4	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech5	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech6	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech7	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech8	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech9	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30
Tech10	OmniTech	Dummy.Minor Repair, Dummy.Major Repair	06:30-17:30	12:00-12:30

Figure 5.3 - Before



Vessel: [redacted]

Tech Team 1: Tech1 ⊖, Tech2 ⊖, Tech7 ⊖

	Work Order Number	Turbine Number	Min Techs	Max Techs	Description	Remaining Time [mh]
⊖	12345678	ID 01	2	6	Test failure	8.00
⊖	13467925	ID 01	2	4	Test inspection	4.00

Tech Team 2: Tech3 ⊖, Tech4 ⊖, Tech9 ⊖

	Work Order Number	Turbine Number	Min Techs	Max Techs	Description	Remaining Time [mh]
⊖	19537248	ID 07	2	6	Test failure	8.00
⊖	66482653	ID 04	2	4	Test inspection	4.00

Vessel: [redacted]

Tech Team 1: Tech5 ⊖, Tech6 ⊖

	Work Order Number	Turbine Number	Min Techs	Max Techs	Description	Remaining Time [mh]
⊖	27795346	LN 02	2	6	Test failure	8.00

Tech Team 2: Tech10 ⊖, Tech8 ⊖

	Work Order Number	Turbine Number	Min Techs	Max Techs	Description	Remaining Time [mh]
⊖	34567890	LN 03	2	4	Test inspection	2.00
⊖	19575315	LN 12	2	4	Test inspection	4.00

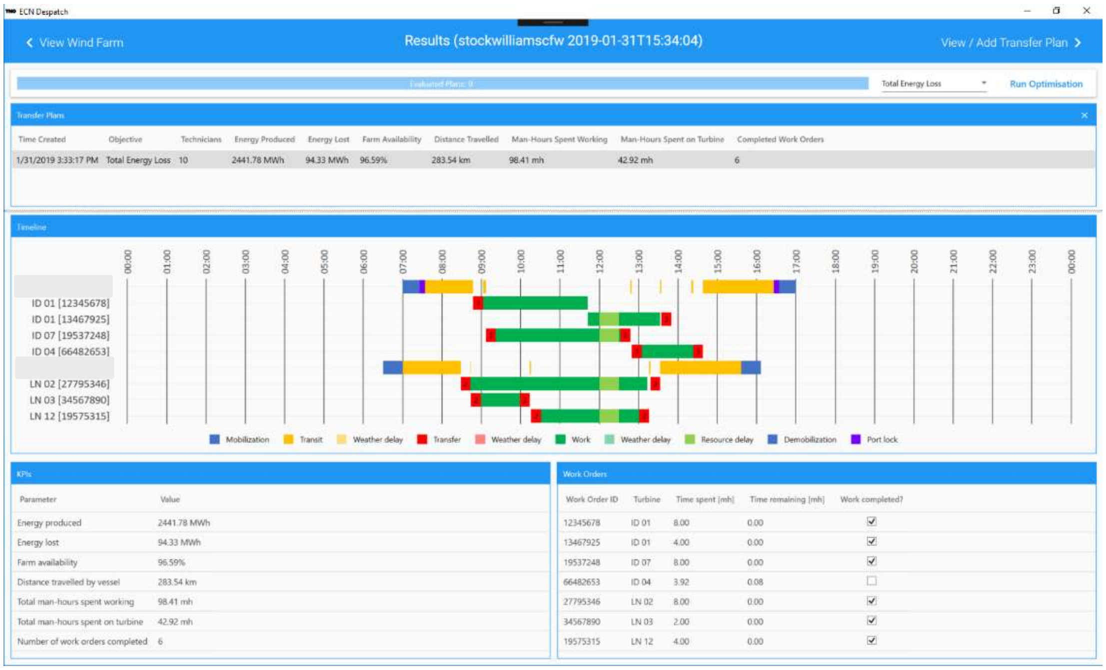
Work Order Number	Category	Turbine Number	Min Techs	Max Techs	Description	Remaining Time [mh]

Technician Name	Technician Type	Technician Skills	Work Time	Lunch Break

Figure 5.4 - After

Finally the simulation is run and outcome displayed, as shown below in Figure 5.5. The screen is split into three sections:

1. The top section contains a list of all transfer plans tried. They can be sorted by various KPIs in order to make a final decision.
2. The middle section shows a Gantt chart of the selected transfer plan. Mouse-over tooltips provide additional information about, for example, vessel speed and technicians on board.
3. The lower section shows more detailed KPIs for the selected transfer plan. For example, the total energy output (left) or amount of work performed on every open work order (right).



Time Created	Objective	Technicians	Energy Produced	Energy Lost	Farm Availability	Distance Travelled	Man-Hours Spent Working	Man-Hours Spent on Turbine	Completed Work Orders
1/31/2019 3:33:17 PM	Total Energy Loss	10	2441.78 MWh	94.33 MWh	96.59%	283.54 km	98.41 mh	42.92 mh	6

Parameter	Value
Energy produced	2441.78 MWh
Energy lost	94.33 MWh
Farm availability	96.59%
Distance travelled by vessel	283.54 km
Total man-hours spent working	98.41 mh
Total man-hours spent on turbine	42.92 mh
Number of work orders completed	6

Work Order ID	Turbine	Time spent [mh]	Time remaining [mh]	Work completed?
12345678	ID 01	8.00	0.00	☑
13467925	ID 01	4.00	0.00	☑
19537248	ID 07	8.00	0.00	☑
66482653	ID 04	3.92	0.08	☐
27795346	LN 02	8.00	0.00	☑
34567890	LN 03	2.00	0.00	☑
19575315	LN 12	4.00	0.00	☑

Figure 5.5 – Transfer plan outcome

On the vessel list on the first screen, each vessel can have its SPOWTT vessel motions information turned on or off. By default, basic weather parameter thresholds and a constant speed are supplied in the background database. With the vessel motions in use, however, the appropriate speed (or none) is looked up regularly during the voyage, depending on the vessel's current heading and the weather.

This file can be created directly by a user by specifying a text file with weather conditions and the resulting vessel speed, similar to a P-plot. It can also be generated from the more sophisticated vessel motions table provided by MARIN, using a pre-processing software tool which can be supplied free-of-charge by TNO on request. The user selects the sickness parameter (e.g. University of Hull's SPOWTT equation, or MSI) and threshold they want to apply, where these are available in the lookup table. The pre-processor then chooses the appropriate vessel thrust (or none) which maintains technicians below the selected seasickness threshold for every sea state. The weather conditions can also be reduced if they are not all available in the forecast.

TNO does not intend to supply the full graphical user interface product standalone, since direct integration with computerised asset management systems (CMMS) is necessary to achieve a fully functional product. However, the ECN Despatch simulation software (without graphical user interface) is available – with high-quality documentation and professional support – for integration by third parties into their software. This product is under continuous development in many projects, both research (such as SPOWTT) and commercial, and has several features not described or developed here, such as automatic transfer plan optimisation.

5.2 Testing

During the SPOWTT project, testing on site with planners was undertaken. A protocol was developed for conducting user trials of Decision Support Systems and obtaining user feedback, specifically within the context of daily operation of offshore wind farms. The protocol contained general considerations for conducting user trials and collecting feedback within an operational setting, and a methodology to be put into practice within SPOWTT WP7, with the goal of testing and validating the ECN Despatch tool developed in WP5. This protocol should be considered for use beyond the SPOWTT project.

The methodology (see TNO report 2019 R10318 for more details) comprised:

- A designated trial period;
- On-site training and familiarisation with the DSS prior to the start of the trial;
- Semi-structured workplace interviews and observations at the start and end of the trial and every 2-3 months throughout;
- Regular prompted feedback from users using a simple (weekly or bi-weekly) online survey; and
- Immediate user-driven feedback using either:
    - Existing external tools e.g. MS OneNote (quick and easy to implement); or
    - An integrated feedback button and form within the DSS software (requires time and budget to implement, but more convenient for the user, and therefore more effective).

TNO staff thus spent a number of days on-site at three wind farms, training staff and configuring the software for ease of use. Only two of the sites were able to proceed with using the software for operational reasons, with only one of the sites engaged with the software beyond the installation period and was able to provide some feedback. This feedback can be summarised as follows:

- The User Interface design is pleasant and easy to use, and particularly clear to generate reports.
- The tool helped the planners foresee disruptions to total time on turbine caused by weather.
- The Gantt chart was particularly useful to determine when the second team to be dropped off would arrive. The tool proved accurate in predicting this, even without vessel motions information.
- The concept of considering energy loss is now a regular part of the daily planning process, and energy price is also entering the picture. ECN Despatch provides an easy way to calculate and understand the consequences of operations and maintenance on these KPIs.
- Forecast confidence is an important factor when decisions are made. Incorporating uncertainty in the forecasted plan could be useful in making planning decisions earlier.

The main barriers to testing experienced by the site were the extra time required to input work orders, without a direct link to the CMMS (in this case SAP), and the lack of direct link to a StormGeo subscription (which was later mitigated by implementing StormGlass).

5.3 ATLANTIS

During SPOWTT, SMC received the transfer plan simulation part of ECN Despatch, in the manner just described, for integration into their ATLANTIS™ marine co-ordination software. The SMC ATLANTIS™ software module integrates with SMC's ATLAS™ Marine Coordination software to provide a holistic planning and implementation tool. ATLANTIS™ is designed to provide a user-friendly platform that supports Marine Coordinators and Planners in their planning decisions, aiming to improve operational safety and efficiency. ECN Despatch acts in a flexible way as a backend simulation support for several features in this software regarding long-term and short-term decision making.

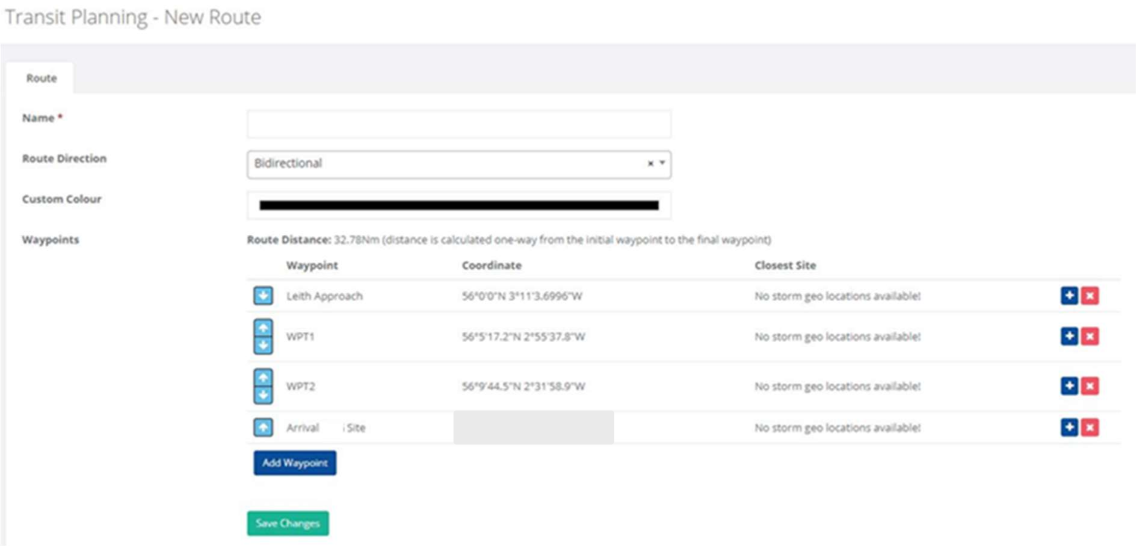
ATLANTIS™ considers predefined routes between mobilisation port and site (and vice versa), as well as weather forecast data to determine the potential impacts of transit on vessels and personnel, as shown in figure 5.6 below.

MAP SETTINGS

Assets	ON
Vessels	ON
Named Locations	ON
Exclusion Zones	ON
Cable Routes	OFF
Project Status	ON
Defects	ON
Pax Counts	ON
Asset Permits	ON
Vessel Permits	OFF
Vessel Labels	OFF
Locations	OFF
Waypoints	ON
Journey Routes	ON

Figure 5.6 – Predefined route

ATLANTIS™ allows users to develop transit routes with multiple waypoints. By doing so, users are able to replicate transit passages to and from site, navigating both geographical and human defined boundaries (e.g. shipping lanes). By splitting journeys into a series of legs, area-specific limitations can be imposed. Users will have the ability to input real-world impositions such as speed limitations when transiting in specific areas (e.g. through port transit). Example shown below in Figure 5.7.


Transit Planning - New Route

Name *

Route Direction Bidirectional

Custom Colour

Waypoints

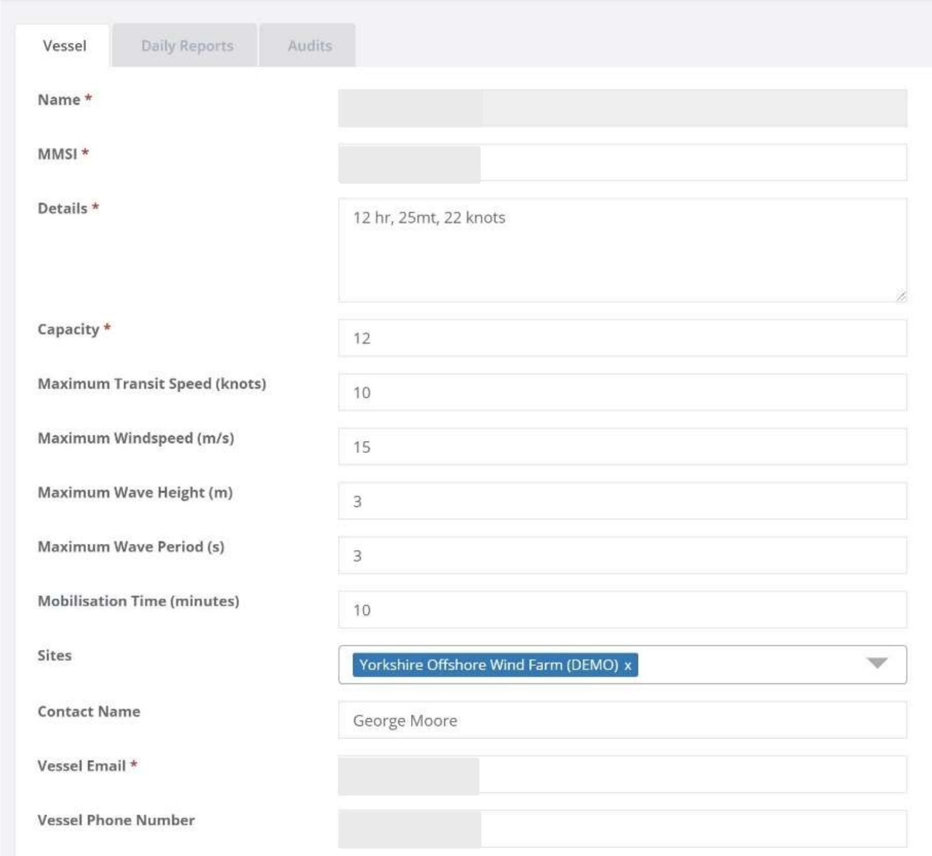
Route Distance: 32.78Nm (distance is calculated one-way from the initial waypoint to the final waypoint)

Waypoint	Coordinate	Closest Site
Leith Approach	56°0'0"N 3°11'3.6996"W	No storm geo locations available!
WPT1	56°5'17.2"N 2°55'37.8"W	No storm geo locations available!
WPT2	56°9'44.5"N 2°31'58.9"W	No storm geo locations available!
Arrival Site	[redacted]	No storm geo locations available!

Figure 5.7 – Speed restriction input

ATLANTIS™ users are able to define journey direction, be it forwards, backwards or bi-directional in relation to the waypoints selected and the order in which they are sequenced. By providing this option, we are enabling the application of the tool in various scenarios, including inter-array transits, single journey transits (e.g. where a CTV may be anchored at site overnight), journeys to and from site with differing entry and exit points, etc.

The ATLANTIS™ tool next allows users to input key vessel data, setting performance parameters against individual vessels which influence the outputs of subsequent journey simulations. As can be seen in figure 5.8 below, vessels are attributed to specific sites, ensuring access to confidential reporting information, for example, is restricted to approved users only. By making only relevant vessels accessible to each user, usability and efficiency is also improved.



Name * [redacted]
MMSI * [redacted]
Details * 12 hr, 25mt, 22 knots
Capacity * 12
Maximum Transit Speed (knots) 10
Maximum Windspeed (m/s) 15
Maximum Wave Height (m) 3
Maximum Wave Period (s) 3
Mobilisation Time (minutes) 10
Sites Yorkshire Offshore Wind Farm (DEMO) x
Contact Name George Moore
Vessel Email * [redacted]
Vessel Phone Number [redacted]

Figure 5.8 – Vessel performance parameters

Through implementation of ECN Despatch, information about technician health and productivity is built into the simulation through the impacts of weather on vessel motion (see section 4.1). Similarly to ECN Despatch, this input can be turned on or off. Motion lookup tables used to provide this information can be imported into ATLANTIS™ by users and subsequently assigned to specific vessels.

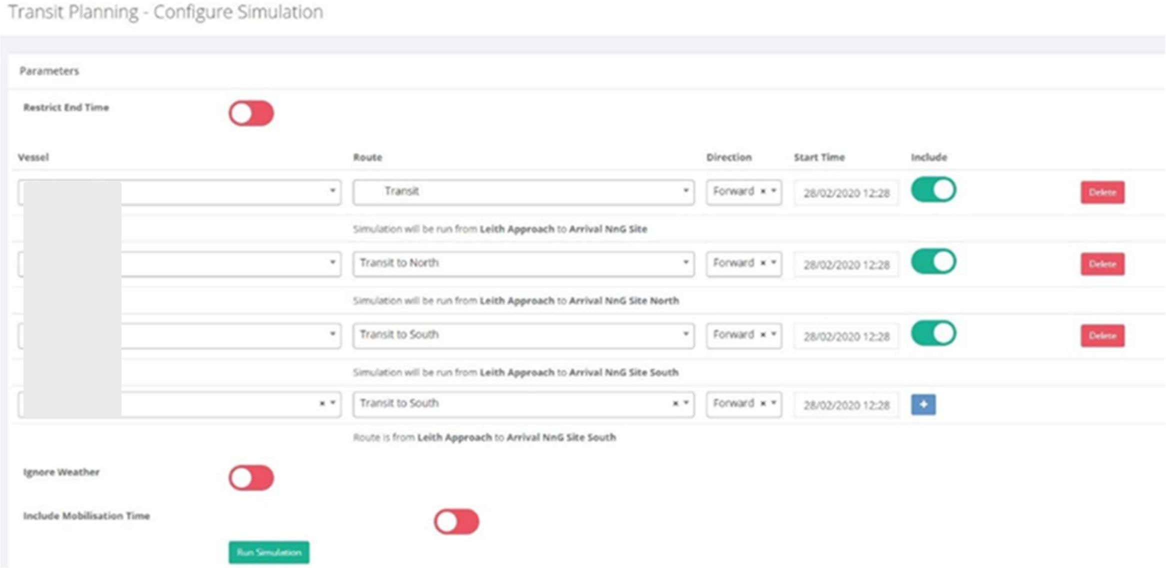
Journey simulations can then be run for multiple vessel types across multiple journeys simultaneously. This application of the tool ensures that users have a clear perspective of simulation results from a single source, supporting swift and effective decision making. See Figure 5.9 below for an example of multiple journeys to different parts of the wind farm.

Figure 5.9 – Multiple journeys

ATLANTIS™ integrates a StormGeo weather forecasting API into the simulation process. StormGeo are widely recognised as the leading provider of weather forecast information to the offshore wind sector and SMC have great experience in utilising their services and confirming the validity of data they have previously provided. ATLANTIS™ automatically references the closest weather reporting location available, in relation to a selected journey, to ensure that the most accurate possible data is employed.

Simulations can be configured to answer questions the marine co-ordinator may have. Simulations are configured by linking vessels to routes, journey start times and any further parameters the user would like to impose, such as:

- Restrict End Time (which can suggest whether or not a journey can be completed within a predefined window. This is useful if technicians need to return to port by a certain time).
- Ignore Weather
- Include Mobilisation Time



Transit Planning - Configure Simulation

Parameters

Restrict End Time

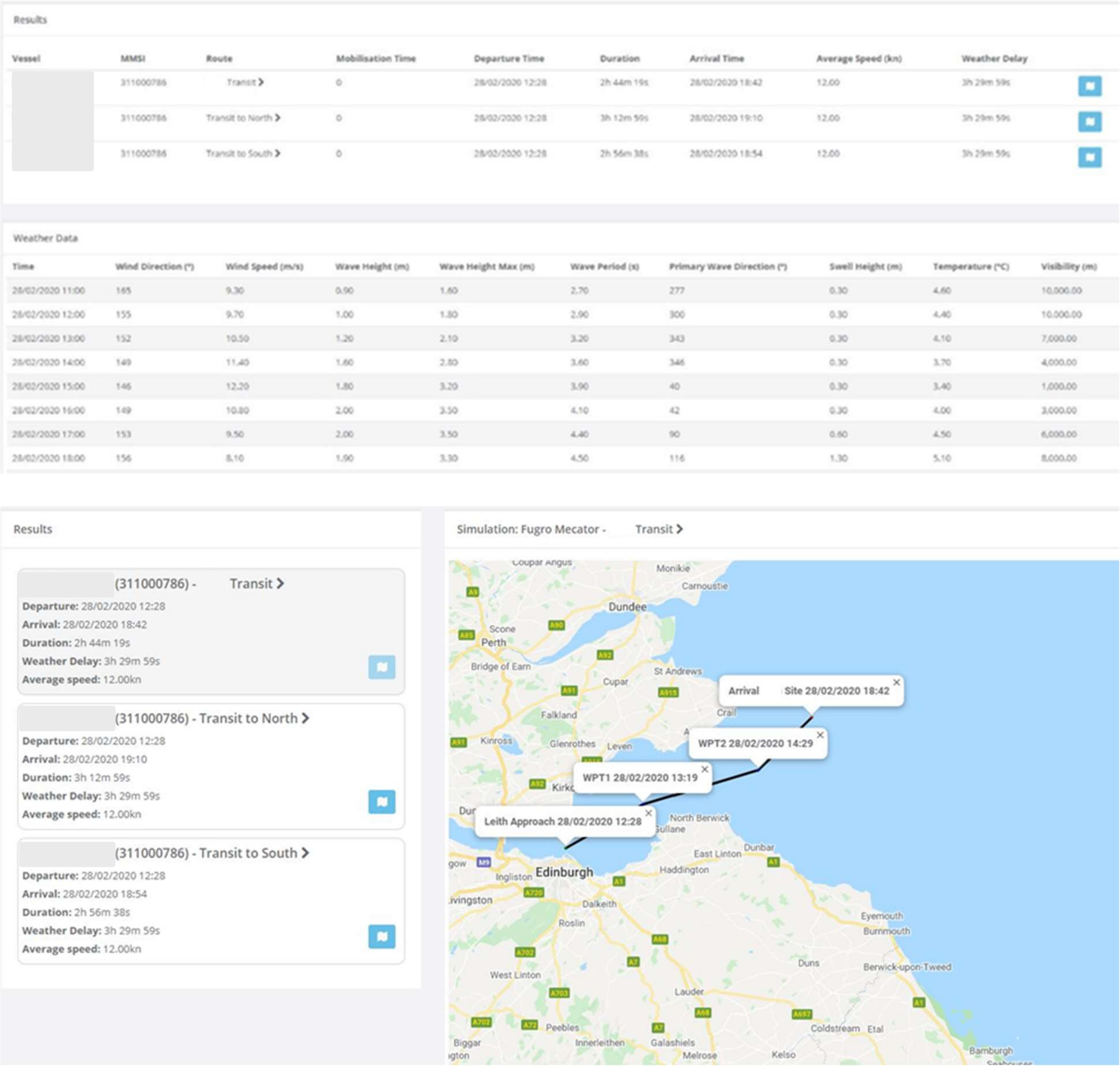
Vessel	Route	Direction	Start Time	Include
[redacted]	Transit	Forward	28/02/2020 12:28	
	Simulation will be run from **Leith Approach** to **Arrival NnG Site**			
[redacted]	Transit to North	Forward	28/02/2020 12:28	
	Simulation will be run from **Leith Approach** to **Arrival NnG Site North**			
[redacted]	Transit to South	Forward	28/02/2020 12:28	
	Simulation will be run from **Leith Approach** to **Arrival NnG Site South**			
[redacted]	Transit to South	Forward	28/02/2020 12:28	
	Route is from **Leith Approach** to **Arrival NnG Site South**			

Ignore Weather

Include Mobilisation Time

Figure 5.10 – Transit planning

Simulation results are presented in a format that ensures a clear comparison of results can be performed by users. The data provided is given in support of the user's decision-making process. By highlighting the journey simulation results on the Map View, users have a clear picture of the predicted journeys and the time implications of weather delays and seasickness speed impositions on them. Waypoint arrival times are highlighted to give further insight into these additional time implications.



Results

Vessel	MMSI	Route	Mobilisation Time	Departure Time	Duration	Arrival Time	Average Speed (kn)	Weather Delay
[redacted]	311000786	Transit ❯	0	28/02/2020 12:28	2h 44m 19s	28/02/2020 18:42	12.00	3h 29m 59s
[redacted]	311000786	Transit to North ❯	0	28/02/2020 12:28	3h 12m 59s	28/02/2020 19:10	12.00	3h 29m 59s
[redacted]	311000786	Transit to South ❯	0	28/02/2020 12:28	2h 56m 38s	28/02/2020 18:54	12.00	3h 29m 59s

Weather Data

Time	Wind Direction (°)	Wind Speed (m/s)	Wave Height (m)	Wave Height Max (m)	Wave Period (s)	Primary Wave Direction (°)	Swell Height (m)	Temperature (°C)	Visibility (m)
28/02/2020 11:00	165	9.30	0.90	1.60	2.70	277	0.30	4.60	10,000.00
28/02/2020 12:00	155	9.70	1.00	1.80	2.90	300	0.30	4.40	10,000.00
28/02/2020 13:00	152	10.50	1.20	2.10	3.20	343	0.30	4.10	7,000.00
28/02/2020 14:00	149	11.40	1.60	2.80	3.60	346	0.30	3.70	4,000.00
28/02/2020 15:00	146	12.20	1.80	3.20	3.90	40	0.30	3.40	1,000.00
28/02/2020 16:00	149	10.80	2.00	3.50	4.10	42	0.30	4.00	3,000.00
28/02/2020 17:00	153	9.50	2.00	3.50	4.40	90	0.60	4.50	6,000.00
28/02/2020 18:00	156	8.10	1.90	3.30	4.50	116	1.30	5.10	8,000.00

Results

[redacted] (311000786) - Transit ❯

Departure: 28/02/2020 12:28
Arrival: 28/02/2020 18:42
Duration: 2h 44m 19s
Weather Delay: 3h 29m 59s
Average speed: 12.00kn

[redacted] (311000786) - Transit to North ❯

Departure: 28/02/2020 12:28
Arrival: 28/02/2020 19:10
Duration: 3h 12m 59s
Weather Delay: 3h 29m 59s
Average speed: 12.00kn

[redacted] (311000786) - Transit to South ❯

Departure: 28/02/2020 12:28
Arrival: 28/02/2020 18:54
Duration: 2h 56m 38s
Weather Delay: 3h 29m 59s
Average speed: 12.00kn

Simulation: Fugro Mecator - Transit ❯

Arrival Site 28/02/2020 18:42

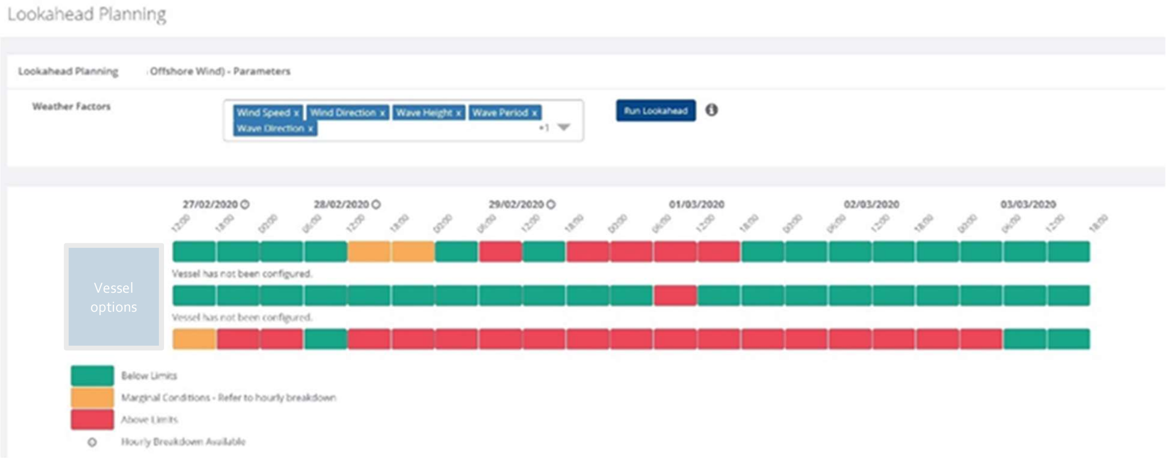
WPT2 28/02/2020 14:29

WPT1 28/02/2020 13:19

Leith Approach 28/02/2020 12:28

Figure 5.11 – Map view

Next, the Lookahead Planning feature within ATLANTIS™ gives users a picture of the foreseen implications of forecasted weather against vessel capabilities. The lookahead planning feature provides clearly presented and easy to process information which can be utilised during planning meetings, 3-day lookahead marine coordination meetings, daily project meetings and others. Ultimately, ATLANTIS™ gives higher confidence in short-term decisions by accounting for forecasted environmental conditions and their effects on vessel motions and seasickness.



Weather Factors: Wind Speed x, Wind Direction x, Wave Height x, Wave Period x, Wave Direction x, +1

Vessel has not been configured.

Vessel has not been configured.

Figure 5.12 – Look ahead planning

There is a comprehensive range of future development possibilities for the ATLANTIS™ planning tool. SMC will continue to implement developments within the ATLANTIS™ software, working with their own experienced marine professionals as well as clients. Following completion of the SPOWTT project, SMC will initially look to implement a vessel selection support tool, using historical vessel performance data held by the ATLANTIS™ tool (accounting for a vessel's proven operability in varying weather conditions) to assess performance and reliability.

The target customer for ATLANTIS™ is a company such an offshore wind farm operator, developer or service provider that utilises either marine coordination or CTV transits as part of their operations. As the market leading provider of Marine Coordination services, SMC will make the ATLANTIS™ tool available to both existing and prospective clients. ATLANTIS™ will act as a USP for SMC and will be promoted as a tool which can work as a standalone product or as a module within the ATLAS™ marine coordination software already maintained by SMC.

ATLANTIS™ will provide scope to save clients capital by optimizing their operations in relation to both vessel utilisation and vessel selection, as well as route and work-order planning. By highlighting the optimal weather windows in which to sail, and the optimal speeds at which to steam, ATLANTIS™ will provide scope for significant fuel usage efficiency improvements and technician productivity gains. Most significantly, ATLANTIS™ supports users in improving the wellbeing of offshore personnel by reducing the negative impacts of transit incurred on individuals. It is vital that the safety and wellbeing of people and the environment is put at the forefront of all operational planning, and ATLANTIS™ can be a key aid in working towards this commitment.

Across 2020, SMC will reach out to the market and demonstrate ATLANTIS™ to potential and existing clients. The tool will be available across all existing and planned marine coordination projects in 2020, which currently totals 11 offshore projects globally, a figure that is expected to rise in the coming months.

6 Dissemination & Exploitation

Spending time and effort undertaking research is only worthwhile if the results are shared widely and then utilised by industry or academia to make a positive impact. The SPOWTT project has uncovered some fundamentally new insight into seasickness and its effect on the wellbeing of individuals working offshore who travel by Crew Transfer Vessel to their place of work. This has implications for a range of organisations and industries and has led to a large number of possible avenues for the project team to explore.

Dissemination

Fundamentally dissemination is about transferring knowledge and results to those who are best placed to utilise it. This will all be publicly available. Below is a table summarising precisely what we are making public, and how one can go about getting access to it. Further information can be found on our SPOWTT website: https://ore.catapult.org.uk/stories/spowtt/

Category	Description	Method	Contact
Reports / recommendations	This report summarising process, findings, lessons learned	Report. Downloadable from SPOWTT website.	Company: ODSL (ORE Catapult) Email: Andrew.stormonth-darling@ore.cataoult.org.uk
Scientific Publications	Joint academic paper – Journal entry (expected)	Submission to journal expected by Q2 2020	Company: University of Hull Email: Terry.williams@hull.ac.uk
	Results on ship motion validation will be made public by journal and/or conference paper(s)	Submission to journal expected by Q2 2020	Company: MARIN Email: g.d.struijk@marin.nl
	UoH impact of psychology	Unknown	Company: University of Hull Email: f.earle@hull.ac.uk
Public access downloads	Website for free download of project findings, including: - Human factors explanation, equations (in reports); - MARIN database/look-up table of predefined vessel types and their associated motions and seasickness rating - TNO programme for pre-processing database; - Source code of App used to collect data during sea trials	Ready Q1 2020	Company: ODSL (ORE Catapult) Email: Andrew.stormonth-darling@ore.catapult.org.uk

	- Source code of on board ‘control measures’ system - MARIN ‘representative hull form’ and its results from both model tests and numerical predictions;		
Events / media	Conference presentations made: - “WindEurope2019” - Copenhagen (Dr Fiona Earle, University of Hull) - “Vessels for Offshore Wind” - Aberdeen - 3rd March (Andrew Stormonth-Darling, ODSL) Conference posters created: - “WindEurope2019” – Copenhagen - MARIN - “WindEurope2019” – Copenhagen - TNO BBC television piece: - Scheduled originally for March 2020 – postponed due to coronavirus - Interviews from Andrew Stormonth-Darling (ODSL) & Dr Fiona Earle (Hull) Industry event: - Webinar / Q&A with industry e.g. roundtable - Organisation dependent on coronavirus impact	Various Could be face-to-face, or virtual e.g. webinar or roundtable video conference	Company: As relevant Email: As relevant

Website downloads in more detail:

What is it	File type	Why might it be useful?
Human factors explanation, equations (in reports)	PDF	Provides full explanation of how the seasickness formula was derived. This can be used to inform future research or can be coded into new site operational planning tools.
MARIN database/look-up table of predefined vessel types and their associated motions and seasickness rating	Excel / csv.	Core information that can be used in other software developed to inform vessel selection.
MARIN ‘representative hull form’	CAD file	Free to use design information for typical CTV hull. Can inform future design work.

TNO programme for pre-processing database	.exe	Essential part of adapting a raw set of vessel motions, with motion-sickness information, into a maximum sailing speed for the given vessel types.
Source code of App used to collect data during sea trials	Code	N.B. It should be noted that this code provided is the result of research and development and should be treated as such. It is not a commercial product.
Source code of on board ‘control measures’ system	Python	Future development / use by other parties to inform decision making during sailing

Exploitation

Exploitation centres around the realisation of the value and impact of the research undertaken. Hence it is important to describe what will and could be delivered following on from the dissemination of results, and by whom. As summary of such activity is made below:

Category	Description	Contact
End products	SMC marine coordination tool – “Atlantis”. As a result of the project this is now available as commercial product for industry. This is detailed further in a separate exploitation plan.	Company: SMC Email: george@smchse.com
	TNO’s “ECN Despatch” planning software – The transfer plan functionality of this tool was developed through the project and is implemented in part in the SMC Atlantis tool. The Despatch functionality itself however is to be developed as a separate tool to be sold to industry.	Company: TNO Email: clym.stock-williams@tno.nl
Procedures / practices	SPOWTT actionable recommendations for industry. This will include the use of control measures, seasickness management techniques, operating procedures, use of decision support tools in practice. This will allow SGRE and owner/operators to reduce and mitigate potential health and safety impacts associated with offshore wind, improve site productivity and reduce operating costs.	Company: SGRE Email: joana.godinho@siemensgamesa.com
Further research	MARIN will use the findings from the validation effort to further improve its prediction methods on ship motions and sea state definition	Company: MARIN Email: g.d.struijk@marin.nl
	The University of Hull will use the experiences and understanding gained from this work to build on established academic excellence in the field of psychology	Company: University of Hull Email: f.earle@hull.ac.uk

	MARIN will continue to develop and refine the onboard control measures system. Further development to include recommended corrective action feature	Company: MARIN Email: g.d.struijk@marin.nl
	BMO aims to use the MARIN hydrodynamic database for further vessel motion studies and offer more validation data to MARIN.	Company: BMO Email: hans.van.heemst@bmo-offshore.com
	BMO will use the seasickness model of SPOWTT for further prediction modelling and continue the validation of the derived model.	
	BMO and MARIN are exploring if there are possibilities to continue research ideas which were initiated during the project but considered out of scope for SPOWTT.	
	TNO are currently leading development of a Dutch collaborative research project which will apply and extend the ECN Despatch concepts for larger, further-offshore wind farms: which rely not on small crew transfer vessels (c. 20m length), but on larger service operation vessels (c. 80 length).	Company: TNO Email: clym.stock-williams@tno.nl
	TNO study to investigate whether fitness of individuals has an adverse impact on likelihood of seasickness	
	Study with major owner/operator investigating fatigue and wellbeing in offshore wind technicians, comparing SOV-based with CTV-based technicians	Company: University of Hull Email: f.earle@hull.ac.uk
	The development of an industry recognised occupational stress risk assessment Workshop planned in 2020, led by G+, Aura, the Energy Institute, HSE and the UoH, to work with industry partners to explore psychosocial risks in offshore wind	Company: University of Hull Email: f.earle@hull.ac.uk
	Use of app code for future projects	Company: ODSL (ORE Catapult) Email: Andrew.stormonth-darling@ore.catapult.org.uk

7 Lessons Learned

This was a large project, with a complex set of stakeholders and long timeframe. It included technological development in various different ways, delivered by a set of multiple, geographically diverse partners. Throughout this process there have been ups and downs and it is important to record the highlights of these in the cases where there are observations that can be made which could be applied to aid future projects. In the below section we cover some examples of positive experiences as well as examples of where things could have been improved.

Positive observations

1. Project Meetings

Generally, the project team have worked effectively together, especially when face to face. In-person consortium meetings were held every 3 months, with regular weekly or bi-weekly conference calls in between. These helped to ensure that all members were up to speed with important developments and allowed the team to get to know each other on a personal level.

Recommendation: Hold face-to-face consortium meetings at least every 3 months, rotating the hosting of the meeting between project partners.

2. Value of interdisciplinary collaboration

It is noted that one of the lessons from the study was the importance of taking an inter-disciplinary approach, and particularly incorporating the lived experience of the technicians. The former was done very well by the project team and furthered our understanding significantly. On the latter, because of distances involved, shift start and finish shift times, substantial technician work volumes during summer months, and the requirement to respond on short notice to operational changes (inherent to the industry), access to the technician workforce was sometimes problematic. However, the different perspectives of those in the project team was hugely valuable in designing our approach.

Recommendation: When visiting technicians at windfarms, due consideration should be given to the frequent operational changes at site. It would be beneficial to design into the project from the start, the ability for project team members to be able to react very rapidly and at short notice to site requirements. Further research should build upon this to enable a more comprehensive input from the technicians.

3. Value of on-site presence

On-site presence during development and testing of the decision support systems proved valuable for several reasons:

- It enabled researchers to gain a far richer understanding of how decisions are made at the various sites, including (the interaction between) the various personnel, systems and tools which are involved.
- It enabled the SPOWTT tools to be adapted to the needs of each site, and integrate with the specific systems/tools already in use. Also, problems in the set-up of the tools could be addressed immediately.
- Site personnel were happy to share their knowledge and experience in the presence of the researchers, but finding time to do this remotely proved very difficult.

Although a limited amount of qualitative data was collected during site visits, and little feedback was provided by sites afterwards, a number of valuable lessons were learned. Referring back to the general considerations for user trials in an operational setting (as detailed in the protocol), these lessons may be summarised as such:

- Requirements and limitations of the project
    - If on-site development and testing is to be conducted as part of a research project, this should be planned at an early (i.e. proposal/consortium) stage. It is important that adequate budget (including working hours and travel expenses) is included, not just for the researchers, but also for site personnel (see below).
- Support of organisation/management in performing trial
    - Once contact was established with operational site management and personnel, responses towards participation in the trial tended to be positive, due to the perceived (future) value of the tools for their work. In particular, value was attributed to the opportunity to automatically import work orders, thereby simplifying work flow and reducing manual effort (and the consequent risk of error), and to test the effect of weather forecasts on intended travel plans, thereby evaluating the likelihood of successful transfers.
    - However, it was also necessary to gain the support of administrative management, HSE, legal departments, and possibly also clients, sub-contractors and vessel operators. This can be a time-consuming process, and should be established as soon as possible, and definitely before commencement of the user trials, with the responsibility for gaining support on the participating wind farm owner or operator, aided by the research organisation.
- Access to (appropriate, representative) users
    - Once researchers were on site, site planners, marine coordinators and other site personnel (e.g. technicians, vessel crews, storekeepers) were happy to discuss their work and participate in observations and interviews, *in the course of performing their normal work duties*.
    - Access to users is necessary, not just for the period of the site visits, but for the duration of the trial period. Several of the site personnel expressed their interest in testing the tool and providing feedback via phone or email for a trial period, but in practice this was not done. The testing and feedback methodology was developed so as to minimise the amount of extra work for the participants, but inevitably places some extra burden.
    - In order for testing without continuous on-site presence to be successful, it is recommended that participants be allocated work time in which to participate. By

    making the sites themselves, not just the umbrella organisation, partners in the project and allocating project hours to them, this challenge could be overcome.
  - Also, this could be further facilitated by integrating (a short period of) testing into the normal workflow by, for example, including it on the daily checklists or to-do lists which were present at each site.
- Access to workplace/site
  - In addition to the above recommendations to plan, allocate budget and gain support for site access at an early stage, flexibility is also necessary. Since availability of site personnel may be dependent on scheduling, weather/sailing days, training and similar, researchers should be prepared to change (travel) plans at short notice.

Recommendation: Whenever possible, qualitative data collection should be conducted in the participants' workplace. Participation of designated sites, including access to sites, participants and data, should be negotiated with all relevant parties at proposal/planning stage. Although flexibility is necessary, adequate budget for working hours, travel and accommodation (if necessary) of researchers *and* working hours of on-site participants should be planned at an early stage.

Challenges

As with any research project, several challenges emerged during delivery which required the team to think laterally and establish solutions for. Some particular examples are presented below.

1. Data collection 1: Motivation of participants

Fundamental to building our model, has been the collection of data from active wind farm sites - without this, there would not be a project. We have employed mechanisms to gather data from various sources including Metocean, heart rates and vessel motions, but it was very difficult to collect the technician data. Fundamental to attempting this was establishing means of engagement and motivation. What the project team found however was that various things should have been noted and planned for at the project design stage, such as the following:

- More moderate expectations should have been made regarding participation rate. This was vastly overestimated;

- The project participants are unable to mandate participation due to the belief that would skew submitted results;

- There are funding body restrictions on the scale of payments (rewards) possible. As a result, the reward mechanisms that were used did not have desired effect;

- The project is unable to incentivise at a more significant scale through payments/ rewards due to tax and compliance reasons;

Engagement & Motivation

Regarding this it quickly became clear to the project team that having an effective 'champion' allocated at each site office was essential to providing daily reminders and encouragement to individuals, to help ensure they used the provided equipment to record information for us. Nevertheless, this strategy proved to be of limited value and impact on the overall volumes of data. With hindsight, the role of the site champion should have been appropriately and clearly assigned to ensure ownership of the tasks. Subsequently, those chosen to be site champions faced numerous challenges whilst endeavouring to balance traditional site duties with project SPOWTT obligations.

In general, initial engagement with sites, and recruitment of participants was very positive, but long-term participation levels were always lower than originally anticipated.

There are potentially numerous reasons for this which include:

- Organisational changes
- Training, supervision and support issues
- Communication issues
- Underestimation of site workloads

Incentives

Regarding this real effort was made to try and establish a system of incentivisation. There were however inherent restrictions to what could be achieved in the fact that both mandated participation and significant financial payment were deemed likely, from a psychological perspective, to skew the legitimacy of the data itself. A small financial reward was however thought likely to encourage participation. In addition, due to likely tax implications, the ability to provide a more meaningful reward was limited. It should be noted that there were other contributory factors to low engagement, which included for example the physiological equipment (chest straps) that were uncomfortable to wear, and IT difficulties as outlined below. This deterred some participants from continuing to take part in the trials.

Recommendation*: Staff allocated, whether from project team or locally at sites, to provide support to the project, where their support is designed into their job profile and time dedicated to the project. Having a regular presence on site at the beginning of the sea trials would be of most benefit. Assistance required would include:*

- Training
- Technical problem resolution
- Engagement
- Communication

It is also recommended that expectations be managed when planning a project, as to what level of data collection is achievable. Project planners should design for a far lower proportion of data returns.

2. Data collection 2: App development and implementation support

Also effecting the collection of data was the performance of the tablet app. A supplier from the Netherlands was contracted to the project to develop the code and build the app, but this particular supplier consisted of only a single individual. Initial app development was undertaken from a high-level concept specification, resulting in rework as more detailed functional requirements became available. As a result, his availability to support with technical issues – often at critical moments – was not forthcoming as our timescales required, which was an additional de-motivator for participants. On top of this, challenges emerged regarding the compatibility of the app with the different iPad configurations used at the sites. Different operating system builds and corporate security restrictions presented some issues with connectivity and functionality. The lack of a common operating platform lead to successful bug resolution at one site introducing issues at another site, requiring further rework and delay. Over the course of the project modifications and enhancements were made resulting in a stable and configurable tool capable of collecting the required data.

Recommendation: *A more robust supplier contract that requires the developer to maintain a satisfactory response rate in order to receive payment. Dedicated data-monitoring teams. Establishment of clear data-monitoring periods. Use of a common platform or early stage alignment between the developer and IT support functions of participating sites to understand/ensure platform compatibility.*

3. Operator willingness to participate

It should be noted also that the buy-in from site owners was essential to participation of sites, and a significant proportion of owner/operators declined to get involved in the project. This was out of the control of the project team

Recommendation: *A more thorough discussion and buy-in from potential operators at project inception.*

4. Inability to make objective 'fitness for work' measurements

It was originally conceived that an assessment of 'fitness for work' could be undertaken to gather data directly from technicians at the point that they were ready to start their work. This would require some tasks to be performed by individuals whilst on the turbines. However, once the detailed delivery of the project began in earnest it quickly emerged that this could not be asked of the personnel as it would interfere too much with the undertaking of the maintenance tasks themselves.

Recommendation: *A more thorough explanation of the practical requirements of the project to be made at the project's inception.*

5. Conflicting definitions

There were some differences in the definition of a particular wave spectrum used by BMO and MARIN. Both parties assumed to be aligned, but MARIN used a definition more suitable to theory, compared to the practical computations used by BMO. This resulted in increased strain on both parties in later stages of the project to rectify the issue under time pressure.

Recommendation: *Make sure that definitions used by multiple parties are put in writing and agreed in earlier stages of the project.*

8 Conclusion

Over the course of more than 2 years, the project team have pulled together and delivered a complex project with many multiple interfaces and challenges.

We originally set out to determine how sailing by CTV to wind farms offshore has an impact on the state of the individuals once they arrive there to start their work. To do this we gathered huge quantities of data, direct from sites, to build an understanding of vessel motions and the impact on the personnel on board. We turned this understanding into a model that was then implemented into decision support tools developed and refined throughout the project lifespan.

One of our key findings is that the impact of vessel motions on seasickness is not driven only by vertical z-axis accelerations, but also by certain frequencies of motion in the y-axis. Frequencies other than 0.16 Hz were found to be impactful, and X-axis movements appeared to have a longer-lasting effect on the day's work.

Through this work we have now created an evidence-based understanding of CTV seasickness, which now implemented into these new operational planning tools, is available to have a direct benefit on the safety and productivity of on-site operations.

Special thanks

The SPOWTT project consortium members would like to thank the following organisations for their contribution and support. Without their input, the project could not have been conducted nor outcomes delivered.

- DEME Group
- NR Marine Services
- Seacat Services
- Turner Iceni
- Windcat Workboats
- Galloper Wind Farm Ltd
- Greater Gabbard Offshore Winds Ltd
- Beatrice Offshore Windfarm Ltd

9 References

Bles, W., Bos, J. E., De Graaf, B., Groen, E., & Wertheim, A. H. (1998). Motion sickness: only one provocative conflict?. Brain research bulletin, 47(5), 481-487.

Bos, J. E. (2011). Nuancing the relationship between motion sickness and postural stability. Displays, 32(4), 189-193.

Brooks, C., Kozey, J., Reilly, T., Cheung, B., & Tipton, M. (2008). Survival at Sea for Mariners, Aviators and Search and Rescue Personnel (RTO-AG-HFM-152).

Calvert Jr, J. J. (2005). Motion sickness, crew performance, and reduced manning in high-speed vessel operations. Masters dissertation, Naval Postgraduate School, Monterey, CA

Cheung, B. (2008). Seasickness: Guidelines for All Operators of Marine Vessels, Marine Helicopters and Offshore Oil Installations. Survival at Sea for Mariners, Aviators and Search and Rescue Personnel, 1.

Dallinga, D., Pinkster, D., & Bos, J. E. (2002). Human factors in the operational performance of ferries. Royal institute of Naval architects (RINA).

Gianaros, P. J., Muth, E. R., Mordkoff, J. T., Levine, M. E., & Stern, R. M. (2001). A questionnaire for the assessment of the multiple dimensions of motion sickness. Aviation, space, and environmental medicine, 72(2), 115.

Hasselmann, K et al, Measurements of Wind-Wave Growth and Swell Decay during the Joint North Sea Wave Project (JONSWAP), Deutsches Hydrographisches Institut, Hamburg, 1973.

Joseph, J. A., & Griffin, M. J. (2008). Motion sickness: effect of changes in magnitude of combined lateral and roll oscillation. Aviation, space, and environmental medicine, 79(11), 1019-1027.

Khalid, H., Turan, O., Bos, J. E., & Incecik, A. (2011). Application of the subjective vertical–horizontal-conflict physiological motion sickness model to the field trials of contemporary vessels. Ocean Engineering, 38(1), 22-33.

Lackner, J. R. (2014). Motion sickness: more than nausea and vomiting. Experimental brain research, 232(8), 2493-2510.

Matsangas, P (2013) The Effect of Mild Motion Sickness and Sopite Syndrome on Multitasking Cognitive Performance. PhD dissertation, Naval Postgraduate School, Monterey, CA

McCauley, M. E., Pierce, E. C., & Matsagas, P. (2007). The High-Speed Navy: Vessel Motion Influences on Human Performance. Paper presented at the Human Systems Integration Symposium, Annapolis, USA.

NORDFORS, 1987, Assessment of Ship Performance in a Seaway

O'Hanlon, James F., and Michael E. McCauley. (1973) Motion sickness incidence as a function of the frequency and acceleration of vertical sinusoidal motion. No. 1733-1. Canyon Research Group Inc Goleta CA, Human Factors Research Div

Pisula, P. J., Lewis, C. H., & Bridger, R. S. (2012). Vessel motion thresholds for maintaining physical and cognitive performance: a study of naval personnel at sea. Ergonomics, 55(6), 636-649.

Reason, J. T. (1978). Motion sickness adaptation: a neural mismatch model. Journal of the Royal Society of Medicine, 71(11), 819-829.

Stevens, S. C., & Parsons, M. G. (2002). Effects of motion at sea on crew performance: a survey. *Marine Technology*, *39*(1), 29-47.

WAFO, a Matlab toolbox for statistical analysis and simulation of random waves and random loads, http://www.maths.lth.se/matstat/wafo/

Wertheim, A. H., Bos, J. E., & Bles, W. (1998). Contributions of roll and pitch to sea sickness. Brain Research Bulletin, 47(5), 517-524.

Appendix 1 Power Spectral Density Estimation

1 Power Spectral Density estimation

The goal of this section is to explain how the continuous-time Power Spectral Density (PSD) $S_{xx}(\omega)$ of a real-valued continuous signal $x(t)$ is estimated by using only a finite amount N of discrete samples stored in $x[k]$. It is assumed the sampling-frequency f_s is known and constant over the signal.

Now, for the part where we estimate $S_{xx}(\omega)$ using a finite amount of samples, we start by calculating the sample-time:

$$\Delta t = \frac{1}{f_s} = \frac{2\pi}{\omega_s} \tag{1}$$

Where Δt is the sample-time in seconds, f_s the sampling-frequency in Hertz, and ω_s the sampling-frequency in radians per second.

First, the Discrete Fourier Transform (DFT) is calculated, which is defined as follows:

$$X[k+1] = \sum_{n=0}^{N-1} x[n+1] \cdot e^{-i2\pi kn/N} \qquad k = 0, \ldots, N-1 \tag{2}$$

Where X is the DFT of x; an array of length N filled with complex-valued numbers. Note that the DFT is usually calculated using the Fast Fourier Transform (FFT) algorithm, which is much more efficient than using eq. (2) directly.

For real-valued time signals, the DFT contains duplicate information. This is the result of the fact that it calculates values for both positive- and negative frequencies, and for real-valued input signals these are simply complex-conjugates of each other. Therefore, we only need roughly half of the values in X to capture all the information. The exact amount of values that we need can be calculated as follows:

$$M = \begin{cases} N/2 & \text{if} \quad N \pmod 2 = 0 \\ (N+1)/2 & \text{if} \quad N \pmod 2 = 1 \end{cases} \tag{3}$$

The discrete-time PSD is estimated by calculating the discrete-time periodogram of the input signal:

$$\hat{S}_{xx,d}[i] = \frac{1}{N} X[i] \cdot \bar{X}[i] = \frac{1}{N} |X[i]|^2 \qquad i = 1, \ldots, M \tag{4}$$

Where $\bar{X}[i]$ is the complex-conjugate of $X[i]$. Note that we only use the first M values of X.

As mentioned before, the DFT calculates values for both positive- and negative frequencies. Therefore, the total power of the input signal at a certain frequency α is spread over α and $-\alpha$ by the DFT, the latter of which has been discarded in eq. (4). To retrieve the total power, we double the discrete-time PSD values for every frequency except the zero-frequency (located at index 1).

$$\hat{S}_{xx,d}[i] = 2 \cdot \hat{S}_{xx,d}[i] \qquad i = 2, \ldots, M \tag{5}$$

The result is a "one-sided" periodogram, in contrast with the "two-sided" periodogram it was before.

To obtain an estimate of the continuous-time PSD, we have to scale the discrete-time periodogram with Δt:

$$\hat{S}_{xx,c}[i] = \hat{S}_{xx,d}[i] \cdot \Delta t \tag{6}$$

The units of the continuous-time PSD are $\frac{g^2}{\mathrm{Hz}}$ or equivalently $g^2 s$, where g is the unit of the input signal x.

The frequency-resolution in Hertz and radians per second are calculated as follows:

$$\Delta f = \frac{1}{T} = \frac{f_s}{N} \tag{7}$$

$$\Delta \omega = \frac{2\pi}{T} = \frac{\omega_s}{N} \tag{8}$$

The frequencies at which we have estimated the PSD are as follows:

$$f[i] = \Delta f \cdot i \qquad i = 0, \ldots, M-1 \tag{9}$$

$$\omega[i] = \Delta \omega \cdot i \qquad i = 0, \ldots, M-1 \tag{10}$$

2 Average Signal Power

The average power P of the input signal $x(t)$ can be obtained by calculating the area under the continuous-time PSD curve:

$$P = \lim_{T \to \infty} \frac{1}{T} \int_0^T |x(t)|^2 dt = \frac{1}{2\pi} \int_{-\infty}^{+\infty} S_{xx}(\omega) d\omega = \int_{-\infty}^{+\infty} S_{xx}(2\pi f) df \tag{11}$$

Where $S_{xx}(\omega)$ is the continuous-time PSD of $x(t)$.

Using a finite number of discrete samples, integrals can be estimated using rectangular integration:

$$\tilde{P} = \frac{\Delta t}{T} \sum_{k=1}^{N} x[k]^2 = \frac{\Delta \omega}{2\pi} \sum_{i=1}^{M} \hat{S}_{xx,c}[i] = \Delta f \sum_{i=1}^{M} \hat{S}_{xx,c}[i] \tag{12}$$

Where $\tilde{P}$ is an approximation of P, $\hat{S}_{xx,c}$ is the one-sided continuous-time periodogram from eq. (6).

3 Variance reduction

Since the variance of a periodogram can be quite large for long signals, we use Welch's method to reduce variance. This method divides the signal into a number of overlapping segments (we use 50% overlap) which are modified using a Hamming window, and a periodogram is calculated for each segment. The segment periodograms are then averaged to arrive at the final result. Welch's periodogram has lower variance, but also lower frequency resolution.

Appendix 2 Description of the numerical approach

Definitions and notations

Throughout this section, the following definitions and notations apply: Environmental (waves, wind, current) directions as input for the simulations are ship-fixed (SF). This means that all environmental directions are given relative to the vessel track as shown in the below figure.

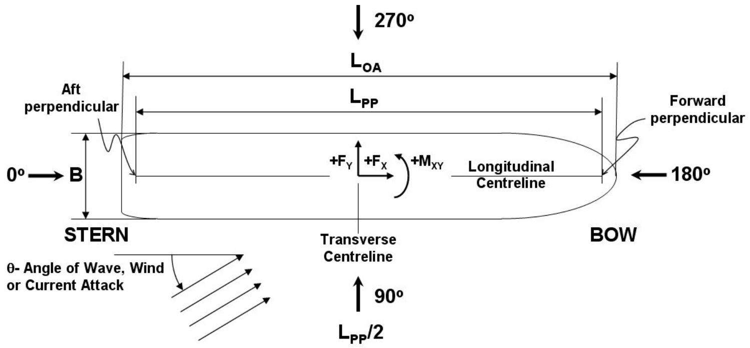


Figure: Ship-fixed coordinate system.

The vessel motions are defined to be positive in the following directions:

surge (x) : towards bow
sway (y) : towards port side
heave (z) : upwards
roll (ϕ) : port side up / starboard down
pitch (θ) : stern up / bow down
yaw (ψ) : bow towards port side / stern towards starboard

The actual environmental conditions (waves, wind, current) are earth-fixed (EF). EF conditions can be converted to SF conditions and vice versa as follows:

$$\alpha_{SF} = \alpha_{EF} - \Psi$$

in which:

α_{SF} : SF environmental direction as used in the hydrodynamic databases

α_{EF} : EF / compass environmental directions, where:
$\alpha_{EF} = 0°$: environmental from South to North
$\alpha_{EF} = 90°$: environmental from East to West
$\alpha_{EF} = 180°$: environmental from North to South
$\alpha_{EF} = 270°$: environmental from West to East

Ψ : vessel heading, where
$\Psi = 0°$: bow pointing to North
$\Psi = 90°$: bow pointing to West
$\Psi = 180°$: bow pointing to South
$\Psi = 270°$: bow pointing to East

Frequency domain (PANSHIP) calculations and RAO databases

The tables below list the hydrodynamic databases generated for five CTVs of varying length.

stage	software	vessel id	origin	speed [kn]
transit conditions	PANSHIP + SBC	CTV-13m	based on real vessel	5, 10, 15, 20, 30
		CTV-14m	based on real vessel	
		CTV-15m	based on real vessel	
		CTV-19m	based on real vessel	
		CTV-20m	based on real vessel	
		CTV-25m	based on MARIN generic model	

Table: Overview of MARIN hydrodynamic databases

description	**symbol**	**CTV-13m**	**CTV-14m**	**CTV-15m**	**CTV-19m**	**CTV-20m**	**CTV-25m**
Length between perpendiculars	L_{pp} [m]	13.67	14.11	14.62	19.00	19.25	25.00
Mean draft	T_{mean} [m]	1.07	1.00	1.21	1.25	1.28	1.30
Longitudinal centre of gravity	LCG [m]	6.18	5.45	6.48	7.78	7.25	10.19
Vertical centre of gravity	KG [m]	1.86	2.17	2.17	2.59	2.50	4.28

Table: main particulars of CTVs

RAO databases were calculated with 'PANSHIP-linear', i.e. assuming a linear relation between the incoming waves and the ship motion response. For each real-world CTV, the hull shape was estimated from available information such as the general arrangement. The transverse metacentric height and the mean draft were received from the participating vessel operators. The radii of inertia were estimated on a best practice basis. For CTV-20m, simulations were done without a trim flap and with a trim flap with fixed angles of 2, 4 and 6 deg. This resulted in different trim angles, as shown in the below figure. The sensitivity analyses with different trim flap angles show sensitivity to the static (mean trim) and dynamic (RMS) motions.

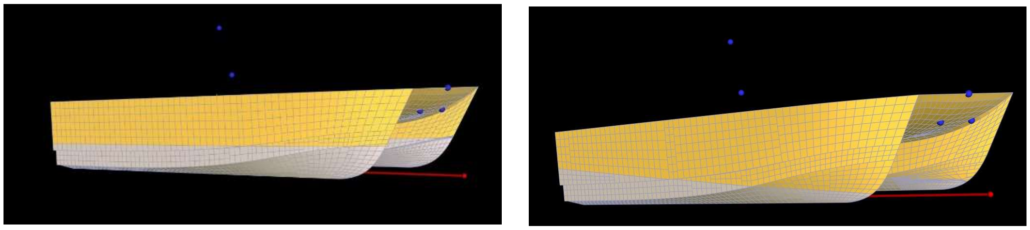


Figure: Effect of trim flap on CTV-20 trim. Left: without trim flap. Right: with trim flap.

Environmental conditions represented by the hydrodynamic databases

The vessel motion response stored in the 'Ship hydro transit db' is calculated for the following conditions:

- 6 catamaran CTV sizes, 13, 14, 15, 19, 20, 25 m, see previous section
- 4 vessel speeds: 15, 20, 25 kn
- Environmental conditions:
  - 384 sea waves:
    - 8 wave heights (Hs): 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00 m
    - 4 wave periods (Tp): 2, 3, 4, 5 s
    - 12 wave directions: 0, 15, …, 330 deg
  - 360 swell waves:
    - 6 wave heights (Hs): 0.25, 0.50, 0.75, 1.00, 1.25, 1.50 m
    - 5 wave periods (Tp): 4, 5 ,6, 7, 9 s
    - 12 wave directions: 0, 30, …, 330 deg

This results in a total of 414,720 conditions for each vessel.

The applied spectral formulation is the JONSWAP wave spectrum, with $\gamma = 3.3$. The effect of wave spreading or so-called short crestedness is taken into by the so-called cos-2s model with $s = 10$.

Calculated signals

The signals calculated for the CTVs consist of:

- Sustained speed in waves
- Motion Induced Interruption (MII), Motion Sickness Incidence (MSI), Motion Illness Rating (MIR), Effective Gravity Angle (EGA).
- Surge, sway and heave acceleration PSD and ESD values at f_1, f_2, f_3 and f_4
- SPOWTT seasickness index
- RMS 3-DOF motions (surge, sway and heave), velocities and accelerations at the crew resting area

Appendix 3 Description of the numerical frequency domain approach

The purpose of this document is to explain the MARIN procedure for calculating the power spectral density of transversal and vertical accelerations at reference points. These quantities are used – either directly or indirectly – in the University of Hull formula for the seasickness parameter as seen in Chapter 3.

The procedure starts with PanShip time domain simulations of ship motions in regular waves. The time traces are used to calculate the linear transfer functions of the motion response, using harmonic analysis. The results is an RAO database containing the linear transfer functions of the ship motion response for a variety of ship speeds, wave directions and wave frequencies. The linear transfer functions are given in terms of amplitude and phase (with respect to the incoming wave height at the ship center of gravity), which can be converted into a complex amplitude.

The following conventions and notations apply:

- The ship center of gravity is denoted by G.
- The ship speed is denoted by U, the unit is m/s.
- The wave frequency is denoted by ω_0, the unit is rad/s.
- The wave direction is denoted by μ, the unit is rad.
- The encounter frequency is denoted by ω_e, the unit is rad/s.
- The complex motion response amplitude is denoted by x, the individual modes are denoted by subscripts:
  - 1=surge=translation along the longitudinal axis
  - 2=sway=translation along the transversal axis
  - 3=heave=translation along the vertical axis
  - 4=roll=rotation about the longitudinal axis
  - 5=pitch=rotation about the transversal axis
  - 6=yaw=translation about the vertical axis

  The corresponding units are
  - m/m for translational modes (surge, sway and heave)
  - rad/m for rotational modes (roll, pitch and yaw)

  m/m resp. rad/m means 'meter resp. rad response (output) amplitude per meter wave height (input) amplitude. For instance: x_4 is the complex amplitude of the roll motion response with unit rad/m. Note that the complex amplitude (which can be represented as a vector in the complex plane) contains information about both the amplitude and the phase of the corresponding time domain response.
- A reference point is denoted by R.
- An acceleration response complex amplitude is denoted by a.

The wave frequency relative to the vessel ie frequency of encounter is calculated as follows:

$$\omega_e = \left|\omega_0 - \omega_0^2 U \cos\mu\right|$$

The reference point position with respect to ship center of gravity is given by:

$$\vec{x}^{(R)} - \vec{x}^{(G)} = \begin{pmatrix} r_x \\ r_y \\ r_z \end{pmatrix} \quad \text{, unit=m}$$

With these definitions we can describe our calculation procedure.

It should be kept in mind that the linear motion response complex amplitude depends in the ship speed, the wave direction and the wave frequency:

$$x = x\left(U, \mu, \omega_0\right)$$

As a consequence, the linear acceleration response complex amplitude also depends on these parameters:

$$a = a\left(U, \mu, \omega_0\right)$$

For the sake of compact notation, we will not write this dependency explicitly.

The absolute transversal acceleration including gravity correction at a reference point R is calculated as follows:

$$a_2^{(R)} = -\omega_e^2\left(x_2 + r_x x_6 - r_z x_4\right) + g x_4 \quad \text{unit=(1/s}^2\text{)×(m/m)=1/s}^2$$

where the factor $-\omega_e^2 = \left(\pm i\omega_e\right)^2$ is the frequency domain counterpart of differentiating twice with respect to time to obtain the acceleration from the motion.

The absolute vertical acceleration at the reference point is calculated as follows:

$$a_3^{(R)} = -\omega_e^2\left(x_3 + r_y x_4 - r_x x_5\right) \quad \text{unit=(rad/s)}^2\text{×(m/m)=1/s}^2$$

The acceleration response power spectrum density is calculated as follows:

$$S_a\left(\omega_0\right) = S_\zeta\left(\omega_0\right) \times \left|a\left(\omega_0\right)\right|^2 \quad \text{unit=(m}^2\text{s)×(1/s}^2\text{)}^2\text{=m}^2\text{/s}^3$$

where $S_\zeta\left(\omega_0\right)$ is the wave height power spectrum density.

The scaled acceleration response power spectrum density (PSD) is obtained by:

$$\hat{S}_a\left(\omega_0\right) = \frac{S_a\left(\omega_0\right)}{g^2} \quad \text{unit=(m}^2\text{/s}^3\text{)} \times \text{(1/(m/s}^2\text{))}^2\text{=s}$$

The scaled significant double amplitude (SDA) is obtained by:

$$\mathrm{S\hat{D}A}_a = 4\int_0^\omega \hat{S}_a\left(\omega_0\right)\mathrm{d}\omega_0 \quad \text{unit=s} \times \text{(1/s)=1}$$

The scaled acceleration response energy spectral density (ESD) is obtained by:

$$\hat{E}_a\left(\omega_0\right) = T\hat{S}_a\left(\omega_0\right) \quad \text{unit=s} \times \text{s=s}^2$$

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