USING SIMULATION TO SUPPORT MANAGEMENT OF OFFSHORE RENEWABLE ENERGY FACILITIES

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ABSTRACT

International commitments to reduce carbon emissions and promote the adoption of renewable energy, has necessitated significant investment in developing wind energy capabilities. The installation, operation and maintenance of offshore turbines presents some unique logistical challenges and costs relative to their onshore versions. This is due to more complex foundations, additional infrastructure and installation requirements, and limited periods of accessibility due to wind and wave conditions. The cost of operations and maintenance (O&M) of offshore wind farms represents 30% of the total lifetime cost of a turbine and is approximately double the O&M cost for onshore turbines. We are developing a simulation-based decision-support tool for rapid modelling, analysing and optimizing the logistics and supply chain requirements for constructing offshore wind generation capabilities and performing the O&M tasks necessary to maintain their availability.

Keywords: energy, offshore wind, optimisation, decision support system

1. INTRODUCTION

Simulation can be of great benefit to the offshore wind industry in the coming years, assisting in the development of logistics for an emerging technology.

With international commitments to reduce carbon emissions and promote the adoption of renewable energy, wind energy usage is on the increase. The European Wind Energy Association (EWEA) forecasts that in 2030, there will be 400GW of wind power capacity installed in Europe, of which 150GW will be onshore and 250GW offshore, which could meet 28.5% of total EU demand (EWEA, 2011), which would see an increase from the 6.56GW installed capacity in Europe in 2013 (EWEA, 2013). The US has as yet no offshore installations, although projects are in development (Wind and Water Power Technologies Office, 2014). The International Energy Agency forecasts that by 2050 offshore wind turbines will account for one third of all wind energy generated (Philibert & Holttinen, 2013).

However, the installation, operation and maintenance of offshore turbines presents additional logistical challenges and expenses relative to their onshore versions, due to more complex foundations, additional infrastructure and installation requirements, and limited periods of accessibility due to wind and wave conditions (Hahn & Bloch, 2013).

The major components of an offshore wind turbine are considered to be the foundation, tower, nacelle (machine house), rotor hub and blades (Lange, Rinne, & Haasis, 2012).

The majority of current turbines use a monopile foundation, but with additional support needed with increasing depths and distance from shore, other structures such as jackets and tripods may be used, or even floating turbines such as Statoil's Hywind concept (Statoil, 2009). These structures are illustrated in Appendix A.

Various factors need to be taken into account when considering the supply chain requirements for offshore wind farms; location of manufacturers, transport to port, construction at port, port infrastructure readiness, type of assembly required, and cost and availability of vessels used for transport, assembly and maintenance of the turbines (Hahn & Bloch, 2013).

As the cost of chartering vessels for offshore wind farms can be extremely expensive, running into hundreds of thousands per day (Dalgic, Lazakis, & Turan, n.d.), it would therefore be prudent to plan installation and maintenance to minimise these costs, and to this end the use of simulation for decision support will play an important role.

This paper will give some background to the use of simulation and optimization in the area of offshore wind, and outline planned simulation tools to support management of this growing area.

2. BACKGROUND AND RELATED RESEARCH

While offshore wind is still a young technology, some work has already been carried out on the use of simulation and optimisation to support its logistics. Existing work in this field will be described below.

Hofmann’s review (Hofmann, 2011) of decision support models concludes that here are numerous decision support models for all aspects of an offshore wind farm, but few covering the entire life cycle from construction to decommissioning. This review considered support structure, electrical infrastructure, transport, weather, wake, maintenance strategy and failures, and found that no model in the review considered all of these aspects.

Hagen (Hagen, Simonsen, Hofmann, & Muskulus, 2013) presents a multivariate Markov chain models for generating sea state time series for use in generating weather data for offshore wind farm simulations, considering significant wave height, wind speed, wave period, wind direction and wave direction.

2.1. Installation Phase

Lange (Lange et al., 2012) presents a simulation tool which models the supply chain for offshore wind turbines accounting for production and transport networks, land and sea resources, and weather. Various aspects are taken into consideration:

Assembly strategy – Several techniques are described. Star assembly involves the hub and rotor blades being assembled on land and transported horizontally to the wind farm. This requires large areas of space for storage and transportation. It uses a single but more complex lift for the blades, requiring longer conditions of favourable weather. Bunny assembly may be used for smaller installations. In this case, two rotor blades are connected to the hub on land and mounted on the plant before adding the third blade. This requires less width in the waterway for transportation, but is used only for installations less than 3MW. Single blade assembly is also mentioned as being under development, in which case the hub is first mounted, followed by each blade individually. This method allows blades to be transported above each other on racks, reducing footprint required in harbours and vessels.

Logistic strategies – the principal strategies used are pendular, in which installation vessel transports a number of components to the wind farm, carries out installation and returns to base port after the installation process, and feeder, in which the installation vessel is located at the wind farm site and components are brought to the wind farm from one or more ports by feeder vessels.

Consolidation vs accumulative transport – using the consolidation method components are produced in various sites and shipped to one base port; whereas with the accumulative strategy one installation vessel may stop at different ports to collect components en route to the wind farm.

Lange’s simulation tool also considers resources such as lifting equipment, and transport vessel availability. Weather data from the proposed site may be included and used to simulate conditions using Markov chains; wind and significant wave height being of greatest relevance as these mainly determine whether vessels may leave port or perform installations. Processes disturbances are considered based on probabilities of failure.

Scholz-Reiter presents a mixed integer linear programming (MILP) tool for calculation of optimal scheduling for offshore wind farms (Scholz-Reiter, Heger, Lütjen, & Schweizer, 2010)(Scholz-Reiter & Lütjen, 2010), with the intention of minimising the total installation time. This model is limited to a single installation vessel, considering a loading set of how many substructures and top-structures may be loaded in each run, loading times and building times for each run, and considers weather in general periods of 1-3 days [in the example presented. These weather periods are randomly assigned, both with respect to length of weather period, and conditions, having an approximately equal probability of being good (top and substructure installation possible), medium (substructure only possible), or bad (no installation possible)]. This model is also presented as being suitable for short term planning using actual forecasts.

Ait Alla also proposes an MILP model for simulation of the installation of offshore wind farms, considering vessel utilisation, travel times and weather restrictions (Ait-Alla, Quandt, & Lütjen, 2013). This model also considers installation of cable to attach turbines to the grid, which is not accounted for in the previously mentioned models, and allows for multiple vessels. Stock of components is also taken into account (this is also considered in the Lange model, and noted but not taken into account by the Scholz-Reiter model). Weather is accounted for using means of historical data for each month of the year for the past 50 years.

2.2. Operations & Maintenance Phase

Dinwoodie (I. A. Dinwoodie & McMillan, 2014) describes four strategies for vessel procurement and considers the appropriate context for and cost implications of each. In increasing order of up-front costs these are:

1 - Fix on Fail – charter vessel when fault occurs; pay for duration of charted, but long mobilisation periods between failure and vessel readiness may affect turbine production availability.

2 - Batch repair – as above, but vessel charter is delayed until a number of failures have occurred; this involves less charters but greater possibility of revenue loss due to turbine down time.

3 - Annual charter (1-12 months) – failures outside the charter period are not addressed until the start of the next charter.

4 - Purchase of vessels – this has the highest up front cost, but may be an efficient use of funds if the failure rates of the turbines are high enough to ensure the frequent usage of the vessels.

The appropriate selection will depend on various factors, including number of turbines in the wind farm and frequencies of maintenance expected.

Vessel selection strategies are also discussed in (Dalgic, Dinwoodie, Mcmillan, & Revie, n.d.), while charter rates estimation is discussed in (I. Dinwoodie, McMillan, Revie, Lazakis, & Dalgic, 2013).

Rademakers presents ECN's OMCE tool (Rademakers, Braam, & Obdam, 2008), (Rademakers, Braam, Obdam, & v.d. Pieterman, 2009) which may be used to estimate costs of calendar based preventative maintenance (1-2 visits per turbine per year, increasing after turbine is 3-4 years old to account for oil changes in gearboxes or major overhauls), unplanned corrective maintenance (required as a result of equipment failure)and condition based maintenance (in the case of unexpected wear of components, but failure has not yet occurred and downtime of turbine can be planned) over the following the next 1, 2 and 5 year periods, based on observed failure rates of components, degradation state of components, number of available days for repair and costs of labour, equipment and spare parts.

Garrad Hassan (now DNV GL) O2M tool for simulation is described in (Phillips, Morgan, & Jacquemin, n.d.), with particular focus on the effect of wave persistence (average duration of a particular sea state) in a given location.

The NOWIcob model (Hofmann & Sperstad, 2013) (Hofmann & Sperstad, 2014) covers activities in the operation phase of the offshore wind farm life cycle. It considers inputs such as vessel mix (number of vessels used, and buy/rent strategies), maintenance tasks (divided into time-based, corrective and condition based, as in (Rademakers et al., 2008), (Rademakers et al., 2009)), personnel shifts and maintenance base type (whether personnel are located onshore, offshore on motherships, or on vessels which remain offshore for more than one shift), and failure rates. Monte Carlo simulation techniques are used to model unpredictable factors such as weather and electricity prices. The model presents outputs in terms of turbine availability (both time-based [based on operative time and life cycle of turbine] and production based [based on real and theoretical possible energy production]), net present income based on of electricity generated, net present O&M cost, and net present profit.

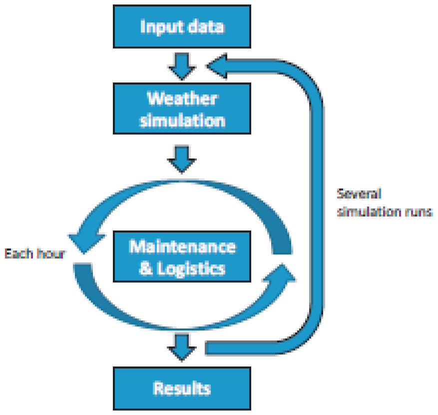

Figure 1: Simplified flow scheme of NOWICOB model

Dinwoodie's (I. Dinwoodie et al., 2013) combined operational and strategic decision support model uses a multivariate auto regressive climate model combined with a Markov Chain Monte Carlo failure and repair simulation to calculate costs (lifetime costs of vessels, revenue loss due to turbine failures etc.), which feed in to Bayesian Belief Networks and decision trees to illustrate the likely eventuality of various risks, and is suitable as a tool facilitate decisions on matters such as whether to purchase or rent vessels, and whether an operator should adopt an OEM manufacturer maintenance contract or carry out its own maintenance.

NOWIcob and the Dinwoodie et al. combined operational and strategic decision support model, along with two others (EDF's ECUME model and University of Stavanger offshore wind simulation model) are verified in (I. Dinwoodie, Endrerud, Hofmann, Martin, & Bakken, n.d.).

Karyotakis (Karyotakis, 2011) considers the effects of a number of parameters (including cost of energy, reliability and energy output), on the cost of energy, reliability and energy output of a wind farm using a planned intervention maintenance policy (equivalent to Rademakers' calendar based maintenance policy), by developing several models, and performing sensitivity analyses on the models for each of the inputs (including accessibility of wind farm, transport costs, decommissioning costs). These models are also validated by comparing them to three real-world wind farms.

Besnard identifies the following factors as critical to the maintenance support organisation of offshore wind farms: 1) location of maintenance accommodation; 2) number and type of crew transfer vessels; 3) use of helicopter; 4) work shift organization; 5) spare part stock management; 6) technical support; 7) purchase or contracting of a crane ship; and considers the first 4 in (Besnard, Fischer, & Tjernberg, 2013), optimising parameters for the maintenance support organisation based on difference between electricity income generated and costs of support teams.

Dewan (Dewan, 2013) proposes a logistic model for inventory management (for calculation of optimum number of spare parts required) and an O&M service model considering turbine reliability, crew and transport strategies, weather and scheduled maintenance. These are solely models, and no not feature optimisation techniques, other than simply feeding in a set of input parameters and inspecting results to determine the most suitable.

2.3. Optimising Operations & Maintenance

Besnard (Besnard, Patriksson, Strömberg, Fischer, & Bertling, 2011) presents a stochastic model for opportunistic maintenance planning of offshore wind farms, using rolling optimisation based upon a 7 day ensemble weather forecast; allowing for optimisation to be performed on a daily basis to update maintenance planning based on power production and weather forecasts. This stochastic optimisation model with one recourse stage is optimised using free MIP solver software and used to plan scheduling for maintenance tasks, given a list of the tasks required to be performed in the next 60 days, using the current 7 day forecast for the short term, combined with seasonal forecasts based on historical data for beyond the 7 day horizon. This model is intended to be used to take advantage of equipment failures and low production forecasts to perform service tasks at the most efficient times; however this model assumes a single maintenance team and requires daily updates from the maintenance planner.

The offshore wind industry is relatively young, and as such, work on optimisation for the supply chain is still in the early stages. The LEANWIND Industry Challenges Report - Supply Chain and Logistics [29] states that developing and maintain a cost-effective logistic system is essential to reduce the O&M costs of an offshore wind farm, and cost-effectiveness in the O&M phase is an important factor for the offshore wind industry to be competitive. The LEANWIND report also identifies developing improved models and tools for logistic concepts as an area which should be explored. It finds that there is a shortage of tools considering the logistic system for offshore wind farms, with [6] being an exception. As this particular tool does not contain an optimisation element, a similar tool incorporating optimisation, potentially with multiple objectives (e.g. time / cost) for installation may prove to be useful. An existing O&M model, e.g. [19] or similar, could also be incorporated, with the addition of multi objective optimisation, considering cost and availability. Current models tend to focus on one particular aspect, or optimisations are limited to a single objective (cost), and it may be advantageous for operators were able to plan to installations optimised based on both time and costs, allowing them to focus their resources more directly; and in the O&M phase to use optimisations based on cost and availability, as government incentives may be related to availability, while the operator would be seeking to maximise its revenue.

The primary focus in this research is on the use of simulation to address the particular logistical requirements of the offshore wind industry; while the use of multi-objective optimisation will be addressed in future work.

3. IMPLEMENTATION OF SIMULATION MODEL

It is proposed to model the supply chain for installation of offshore wind farms, into a simulation tool (which will be an extension of MYMIC's Scalable End-to-End Logistic Simulation [SEELS]) (Mathew, Mastaglio, & Lewis, 2012); and further to construct a tool for the multi-objective optimisation of the O&M phase of the offshore wind life cycle (e.g. cost vs availability of power output – it would desirable to maximise availability, while simultaneously minimising costs.) This optimization tool should also be designed to allow for integration into SEELS.

Initially the focus will be on the extension of SEELS to cover offshore wind farms and their associated transport vessels. The tool may be extended to other forms of offshore renewable energy, once the use case of offshore wind has been developed.

As SEELS is an established tool for logistics, it is proposed to develop architecture for offshore wind based upon the existing SEELS architecture, as partially represented in Appendix A (an extract from the SEELS simulation core architecture). Figure 2 below represents a method in which this structure may be built upon to similarly model offshore wind farms. It uses a class based upon the original Port structure to represent a wind farm Terminal is used as the basis for representation of both an individual turbine (or also an actual terminal in the case of a port with dedicated offshore wind facilities); with OperationalArea in the left branch of the diagram serving as the basis for components of an individual turbine (foundation, tower, nacelle, rotor hub, blades etc.) OperationalArea in the right branch of the diagram representing structures shared across by multiple turbines, or indeed the entire wind farm (offshore maintenance base, grid connections, etc.)

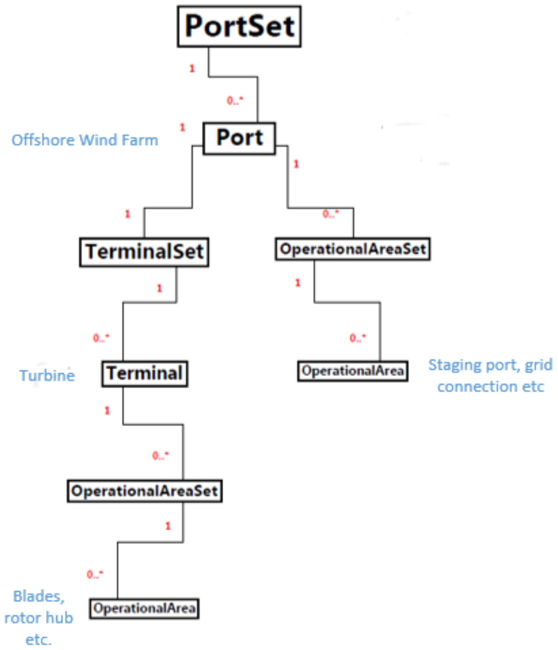

Figure 2: Proposed structure for SEELS extension.

As the components involved in offshore wind are quite large and are transported and assembled using different strategies, it will be necessary to add definitions to vessels and staging areas to define which components they may transport, store and operate on. It will therefore be required to add further

Each component of a turbine will also have parameters relating to particular failures which may occur, e.g. a probability of each such failure occurring on that component within a given timeframe.

The simulation should allow for planned maintenance. Figure 3 below shows a potential process flow – in each time step in which the simulation is running, it will initially determine which turbines require maintenance in that window - those which fail in this window, plus those which on which maintenance was required in the previous window, but was not carried out. Each maintenance task will have a priority assigned to it, so that the tasks which are most urgently required are attended to first. The availability of equipment and components necessary to each task is checked. Weather will be used as an input to the model in some form, hence the accessibility of the turbines requiring maintenance will be determined by ensuring that wave height and wind speeds are not above the thresholds for safe access to the turbines. Finally, the maintenance tasks will be carried out as time allows in the window, starting with those of highest priority. All tasks which are not carried out will be carried over into the next window as still requiring action.

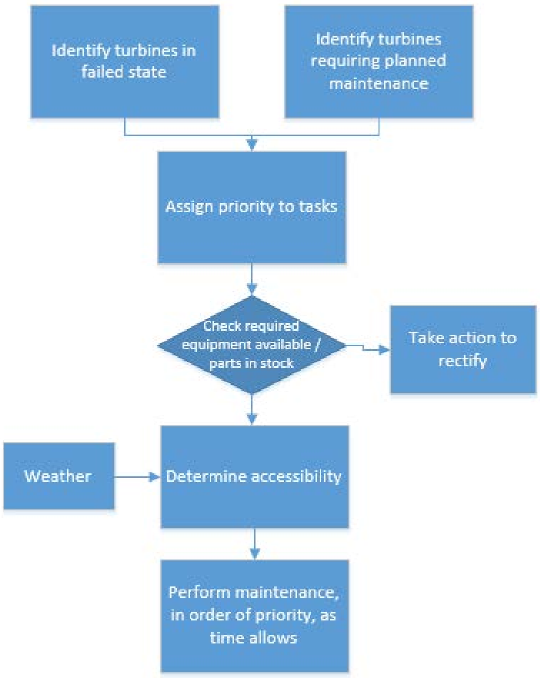

Figure 3 – Proposed process flow for simulation of O&M

4. CONCLUSION

The development of the offshore renewable energy sector in the coming years can be aided by the use of simulation. A proposed simulation tool for the case of offshore wind has been presented.

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APPENDIX A – OFFSHORE WIND FOUNDATIONS / FLOATING STRUCTURES

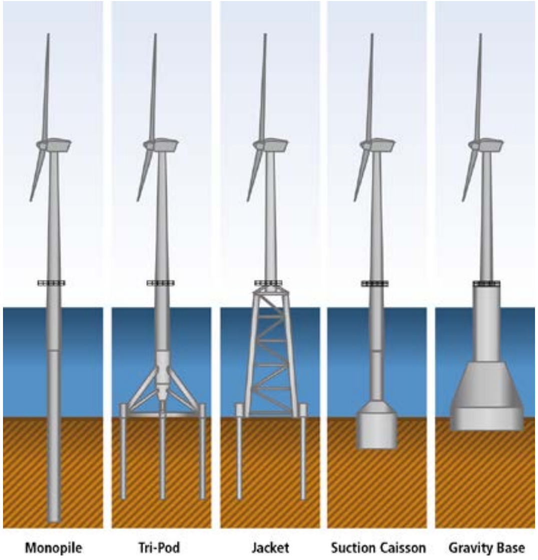


Figure A1 - Foundations

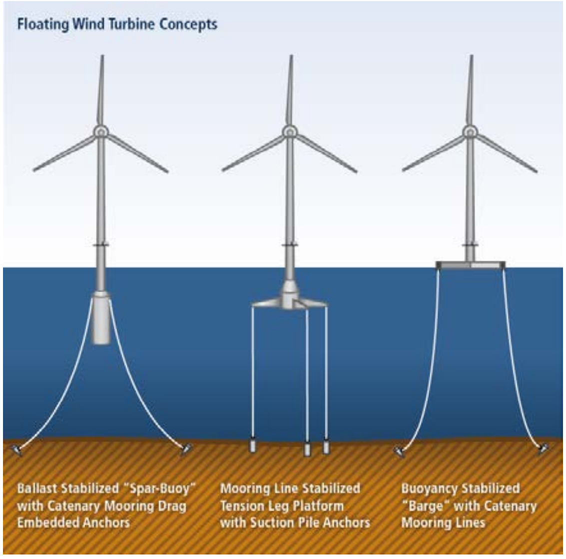
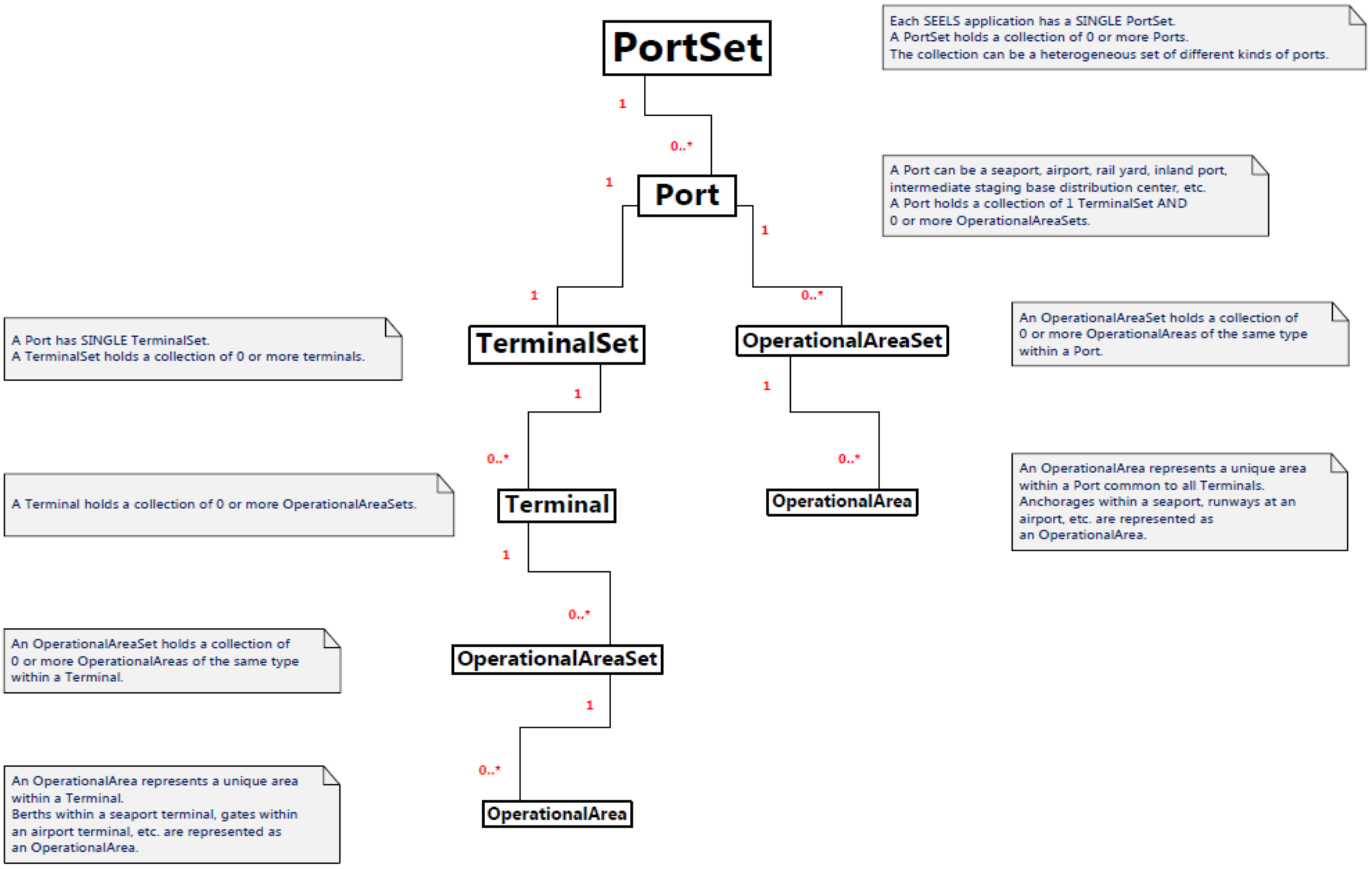


Figure A2 – Floating structures

APPENDIX B – EXTRACT FROM SEELS ARCHITECTURE



Each SEELS application has a SINGLE PortSet.
A PortSet holds a collection of 0 or more Ports.
The collection can be a heterogeneous set of different kinds of ports.

A Port can be a seaport, airport, rail yard, inland port, intermediate staging base distribution center, etc.
A Port holds a collection of 1 TerminalSet AND 0 or more OperationalAreaSets.

A Port has SINGLE TerminalSet.
A TerminalSet holds a collection of 0 or more terminals.

An OperationalAreaSet holds a collection of 0 or more OperationalAreas of the same type within a Port.

A Terminal holds a collection of 0 or more OperationalAreaSets.

An OperationalArea represents a unique area within a Port common to all Terminals.
Anchorages within a seaport, runways at an airport, etc. are represented as an OperationalArea.

An OperationalAreaSet holds a collection of 0 or more OperationalAreas of the same type within a Terminal.

An OperationalArea represents a unique area within a Terminal.
Berths within a seaport terminal, gates within an airport terminal, etc. are represented as an OperationalArea.

Architecture Organization from SEELS Simulation Core Architecture - UML Class Diagrams - Version 6

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