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TNO report

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Offshore Wind Access Report 2022

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Summary

In order to better capture wind conditions, offshore wind farms around the world are moving further away from shore. However, this poses new difficulties for their Operations & Maintenance (O&M). Over the lifetime of an offshore wind farm, larger distances will significantly increase the O&M component of the Levelized Cost of Energy (LCOE). One of the major causes is the decreased workability and access possibilities for O&M vessels and access equipment, which raises the possibility of downtime and subsequently reduces energy output, particularly for far-offshore wind farms. This has encouraged research into novel access technologies for offshore wind farms.

This fifth edition of TNO's Access Report presents an updated overview of various access vessels and systems for accessing offshore wind farms. According to the research in this report, the expansion of this market and the incorporation of new technologies are in line with the need for a safer and more effective transportation of personnel and goods to the wind farms. The importance of modeling the O&M activities in offshore wind farms using the in - house developed O&M Planner tool is highlighted in order to evaluate the impact of selecting a specific access vessel or system.

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1 Introduction

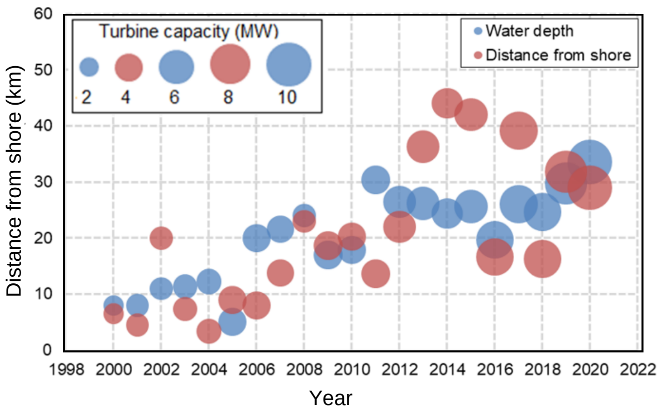

Figure 1: Evolution of distance from shore for offshore wind turbine with turbine capacity (in MW) over time [1]

Offshore wind energy has grown tremendously and is continually moving further offshore into deeper waters. Figure 1 shows the growth of offshore wind turbine capacity (in megawatts) between 2000 and 2020 as a function of global weighted average water depth and the distance from the shore. It shows that earlier in the 2000s, offshore wind projects were built in shallow nearshore waters, but later, the projects moved much further offshore. Moreover, it was also shows that the turbine capacity increased between 2000 to 2020. As a consequence, the Operations and Maintenance (O&M) costs for offshore wind sector have increased, further emphasized by the greater loading and complexity of modern turbines potentially driving higher failure rates.

In an attempt to reduce the O&M costs, new strategies for logistics are being developed using more robust and more sophisticated access vessels and systems. The distance from the O&M port has a large influence on the most suitable strategy, as can be seen in Figure 2. For near-shore wind farms, medium sized Crew Transfer Vessels (CTVs) like catamarans, are most commonly used for daily transit from the port base. As the distance to the offshore wind farm increases, the travel time to these wind farm does as well. Moreover, long trips with CTVs in less favourable weather conditions can cause sea-sickness to the technicians onboard, especially when CTVs travel at high speed. In general, it is preferred to limit the transit time between the port and wind farm to less than one and a half hours, if CTVs are used to transfer technicians [2]. Therefore, far-offshore wind farms require an offshore base for accommodating the technicians and spare parts. Helicopters can also support O&M activities when the use of work-boats leads to a very short working period, or when conditions are too rough for access onto the turbine. The most commonly used offshore O&M base is the Service Operation Vessel (SOV) or Walk-to-Work (W2W) vessel. These Dynamic Positioning (DP, in particular DP2) vessels are typically longer than 50 m and can accommodate up to 75 technicians and small-sized spare parts. Several of them can facilitate landing of a helicopter.

Overall, the goal for selecting the O&M logistics strategy is to achieve the most optimal trade-off between the overall O&M costs and the annual availability of the wind farm. Typically for

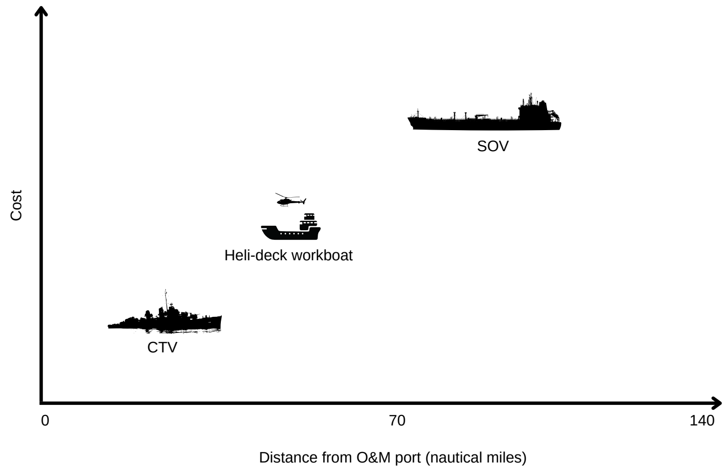

Figure 2: O&M logistics strategy using different access vessels as function of distance from port and cost

offshore wind farms, availability of 95% and higher are targeted to achieve this trade-off. The limitations on achieving higher reliability of components have turned attention towards optimizing the maintenance strategies including the access methods to the offshore sites. The latter is described with the term accessibility, meaning the percentage of time that an offshore wind farm can be approached and accessed by technicians; this is a key element that determines the economic viability of a project where the uncertainties are found to be very high.

Results of studies [3] reveal that accessibility is necessary at least 80% of the time to achieve wind farm availability of over 90%. It should be noted that the calculations regarding the accessibility for ship-based access are determined on the maximum allowable wave conditions during personnel transfer. Wave conditions are generally described by three parameters: the significant wave height (H_s), significant wave length and significant wave period. In Figure 3, a typical temporal distribution of North-East Atlantic Ocean monthly average wave parameters are shown. Such data are used to define the requirements of an access solution to service wind farms in a specific location.

Besides average annual accessibility, the monthly accessibility is also of importance since it indicates the seasonal effect. Figure 4 presents the result of offshore significant wave height H_s for the 56 years of wave hindcast in the southern North Sea. The figure shows that the summer months (April to September) are significantly more accessible than the maritime winter months (October to March). Moreover, the variability in H_s for the summer period, indicated in Figure 4, is much lower than in the winter period.

1.1 Access report overview

TNO's Access report is divided into:

- **Access vessels and vehicles**: The denotation of access vessels and vehicles are collective reference and as such includes a wide array of vessels and vehicles serving variety of purposes in the offshore wind energy sector.

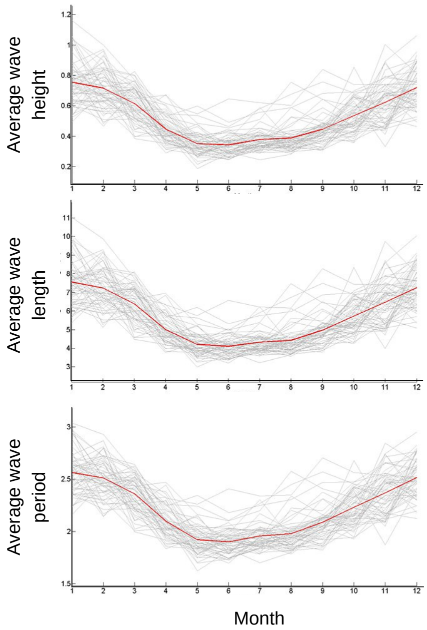

Figure 3: Monthly average values of significant wave height, wavelength and period. Grey lines correspond to individual years, redlines show average values corresponding to the 40 years hindcast period in the Northeast Atlantic Ocean [4]

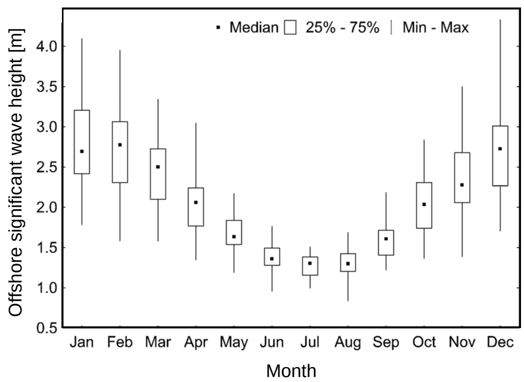

Figure 4: Monthly average of the offshore significant wave height for the 56 years of wave hindcast in the southern North Sea [5]

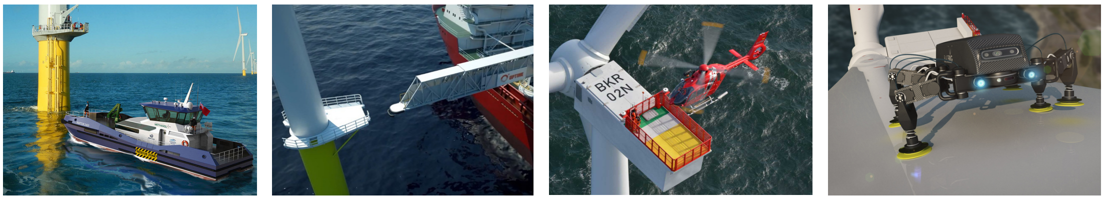

Figure 5: Access to the boat landing, TP platform landing, helideck/hoisting platform and autonomous inspection (from left to right)

- **Access systems**: Access systems refer to the transfer systems typically installed on access vessels that provide safe, effective means for crew and cargo transfer during installation and O&M phases of the offshore wind energy sector.

Figure 5 shows a number of examples for different access vessels and systems. In the chapter 2, different access vessels and systems will be presented. The accessibility of the different commercially available vessels and systems is presented in chapter 3. Chapter 4 demonstrates a reference scenario for the accessibility of offshore O&M activities using TNO O&M Planner tool, followed by conclusions in Chapter 5.

1.2 Objectives and report outline

As highlighted in the previous section, accessibility is crucial for offshore wind farms. Enlarging the operating weather windows for accessing far offshore sites is a key driver for cost reductions in offshore wind: even short standstill periods for large wind turbines have big impact on the business case of the wind farm. Hence, the market for access vessels and systems has evolved rapidly and new technologies are being introduced every year. This work intends to present the existing and new access systems for offshore wind with their specifications.

However, only systems that have either been demonstrated at a prototype level, or are commercially available in the current market will be discussed in this report. To make the distinction between the different systems, the technology readiness level (TRL 1-9) is used, with definitions from EU Horizon 2020 [6]. below mentioned TRLs are relevant for this report:

- TRL 7: System prototype demonstration in operational environment
- TRL 8: System complete and qualified
- TRL 9: Actual system proven in operational environment

For the demonstrated systems TRL 7-8 applies, while for the commercially available systems the highest level of TRL 9 is used. Conceptual designs (below TRL 7) are therefore not included in this report.

1.3 Changes with respect to the 2020 Offshore Wind Access Report

In this edition, the following changes are made with respect to the previous edition:

- Access to Floating Offshore Wind Turbines is discussed [see Chapter 2].
- Autonomous systems used for offshore wind farm inspections and repair activities are discussed [see Chapter 2].
- The information, values and statistics in the previous edition have been updated based on the latest knowledge and updates from the access systems market [see Chapter 3].
- The accessibility assessment of offshore wind O&M is demonstrated using TNO O&M Planner. [See Chapter 4]

2 Access vessels and systems

2.1 Access vessels

The growth of offshore wind farms is pushing the demand for access vessel technologies. The choice of the best access vessel for a specific offshore wind operation can be difficult due to the numerous factors involved, including cost, maximum payload, weather restrictions, emission factor, etc. In the following section we intend to provide information on various access vessels that are currently built or existing for offshore wind farms.

2.1.1 Crew transfer vessels (CTVs)

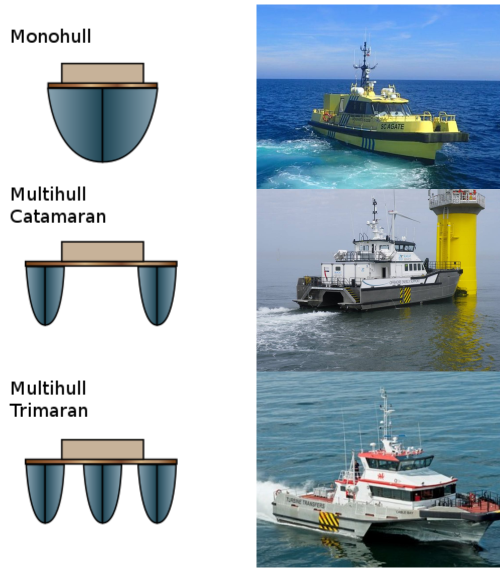

Figure 6: Monohull, Catamaran and Trimaran CTVs [representation] (from top to bottom).

There are many different specialized CTVs that offer access to offshore wind farms. Depending on the sea-keeping ability of each CTV type, they are deployed for wind farms at different distance, but in most cases, for wind farms that are situated close to a port base. The 'bump and jump' method, which eliminates vessel translations by making frictional contact between the vessel's specifically shapd bow with fender and the wind turbine boat landing, is used to transfer personnel. CTVs normally transport 12 to 24 technicians as well as equipment and small replacement parts. Typically, the built-in nacelle crane or platform davit crane of the Transition Piece (TP) is used to lift goods from the vessel deck to the platform. According to the hull form, there are various CTV types, including:

- Mono-hull: The earliest CTVs used in offshore wind farms were mono-hull boats converted from a pool of multi-purpose boats that previously served as pilot and merchant marine support crew tender boats. Their key benefits are their affordability and scalability. However, mono-hull CTVs can only function safely in sea states with significant wave heights of 1-1.2 m due to their inadequate stability when bringing offshore technicians onto the monopile.

- Catamaran: Catamarans made of aluminum make up the majority of CTVs today. Their widespread use can mostly be attributed to their high transit speeds, excellent sea-keeping performance in medium-sized waves, and increased stability when pushed up to a boat landing of a wind turbine for offshore technician transfer. Their relative higher cost makes them less advantageous than mono-hull vessels. Catamaran CTVs can normally function well in significant wave height up to 1.2-1.5 m.
- Trimaran: Trimaran CTVs were introduced to the market to help catamarans maintain better seakeeping behavior. Technical personnel can be transferred up to 1.5–1.7 m significant wave height.
- Small Waterplane Area Twin Hull (SWATH): SWATH CTVs are steadily gaining market share, particularly in the installation and commissioning of wind farms when several groups of technicians must be moved to the wind turbines under potentially high pressure to maximize working time. SWATHs are catamaran-like boats that increase stability by reducing the area of the hull's cross section at the sea's surface. Compared to catamarans, they are slower and more expensive. Their design enables safe access at significant wave heights of generally 1.7-2.0 m while providing comfort during transit.

Figure 7: A SWATH vessel (left) and the distinguishing narrow waterline hull design (right)

- Surface Effect Ship (SES): SES technology has also been adopted for CTVs. SES CTVs have catamaran-like hull shapes, but the majority of the weight is supported by an air cushion, which offers great stability/comfort that permits fast vessel transit speeds, minimal fuel consumption, and good sea-keeping behavior. Nevertheless, this has the drawback of more complex design and more expensive construction. Typically, a SES can function at sea states as high as 2.0 m H_s during the transfer phase. It should be noted that only a very small number of these kinds of vessels have been constructed.

Figure 8: Surface Effect Ship by CWIND

Table 1: Characteristics of CTVs

	Monohull	Catamaran	Trimaran	SWATH	SES
Length [m]	12-25	15-27	19-27	20-34	26-28
Top transit speed [knots]	15-25	18-27	18-22	18-23	35-39
Passenger capacity [-]	12	12	12	12/24	12/24
Cargo [tons]	5-10	10-15	1-5	2-10	3-5
H_s limit [m]	1-1.2	1.2-1.5	1.5-1.7	1.7-2	1.8-2.2

Table 1 shows an overview of typical values of the characteristics of the aforementioned CTV types. CTVs are typically diesel-powered, and the design has primarily emphasized maximizing sea-keeping characteristics while also achieving higher speed and less fuel consumption throughout the transit. There is very little focus on optimizing performance (such as fuel usage) while idling and travelling at a slow speed. The past few years have seen a trend toward electrical, hydrogen, and hybrid propulsion systems as regulations for greenhouse gas emissions have become more serious. Additionally, new hull (shape) designs of CTV are being researched, designed, and prototyped in an effort to reduce emissions and fuel consumption when the CTVs are travelling at low speed.

2.1.2 *Service Accommodation Transfer Vessels (SATVs)*

SATVs are made to stay offshore longer due to the turbines further offshore location. They can in some cases make weekly transits to and from the wind farm as opposed to daily transits. This contributes to lowering the levelized cost of energy Because more technicians can stay on board and spend the night on SATVs, they are larger and perform better at sea than CTVs. However, SATVs continue to operate as CTVs, pressing up against the dock to transfer technicians. The transfer of SATVs between turbines is simpler than that of service operation vessels (SOVs). In terms of cost, design complexity, and operational variety, SATVs are viewed as bridging the gap between CTVs and SOVs.

Figure 9: Service Accommodation Transfer Vessel designed by BMT

Several SATV designs are now being developed (see Figure 9), but only one has ever been constructed: the Ventus Formosa, which was created by BMT in the UK and is now owned by Ventus Marine. The 36.3-meter vessel has a cruise speed of 16 knots, a sprint speed of 19 knots, and can accommodate 10 crew members for a 12-day offshore stay.

2.1.3 *Walk-to-Work Vessel / Service Operation Vessels (SOVs)*

The majority of Walk-to-Work (W2W) vessels now employed in the offshore wind industry are retrofitted oil and gas industry vessels with either permanently or temporarily installed motion compensated gangways. In the installation phase of offshore wind farms, particularly during infield cable installation and wind turbine commissioning, W2W vessels are frequently used. W2W vessels are currently being used more frequently for substation and wind farm regular maintenance activities. Service Operation Vessels (SOVs), which are specially constructed W2W ships devoted to servicing the installation and ongoing O&M of offshore wind farms, have been available on the market since 2015. These purpose-built SOVs typically perform better when it comes to transferring technicians and cargo than retrofitted W2W vessels because they are designed with motion compensated gangways (and cranes, if any) onboard. As a result, design considerations like the location of the gangway/crane, the layout of the deck, and technician/cargo logistics can be optimized.

The use of SOVs for offshore wind farm installation, operation, and maintenance has numerous advantages:

- Since SOVs are stationed offshore close to the wind farm, it takes less time to get technicians to the turbine, extending their effective working time. The working laws in Europe state that technicians who are situated offshore typically rotate their shifts every two weeks. As a result, the SOVs employed in the everyday operation of the wind farm have a consistent workflow. Every two weeks, the SOV returns to port for crew changes, reloading cargo, and bunkering, which typically takes a day.
- Since the technicians on SOVs are stationed offshore, they are able to have a phased work schedule, which means that the technicians working shift can only begin when they are

being transferred to the wind turbine. The SOVs used for wind farm O&M typically have to move many teams of technicians to various turbines within a single day. The working time of technicians who will be transferred later in the day is not diminished because of the vessel's trip or team transfers because of the staggered working schedule. In comparison to the shore-based access method, where each technician's working shift begins when they depart from the port for the wind farm, this extends their actual working hours.

- Longer weather windows for installation, commissioning, or maintenance activities are produced by SOVs' improved accessibility. This means that even when wind farms are close to shore, SOVs are frequently employed during the installation (commissioning) phase of wind farms. Compared to access by boat landing, the motion compensated gangway on SOVs can offer a considerably easier and safer transfer of technicians and freight to the wind turbine. Many new SOVs are adopting a 'step-less' method, meaning that technicians do not need to step up (or down) during the entire transfer procedure from the cargo deck / accommodation to the wind turbine TP platforms, in order to further improve the efficiency and safety during transfer. The step-less approach also enables the movement of small freight (200 kg) using trolleys or pallets. Generally speaking, the motion compensated gangway and the integrated lift in the SOV help achieve this step-less approach.
- The better sea-keeping characteristics of SOVs compared to CTVs result in less motion-induced tiredness in technicians, which improves technicians' performance.

Figure 10: Walk-to-Work vessel Vroon VOS Start

SOVs also have some disadvantages:

- CTVs are significantly less expensive than SOVs. A SOV's day rate is roughly 8–10 times greater than a CTV's. This is the prime motivation for the continued use of CTVs in the majority of near-shore wind farms. Since technicians can operate in two shifts (day and night) during the installation phase of a wind farm, the high expenses of SOV can be halved by utilizing it twice as effectively. The O&M phase, where technicians often exclusively work during the day shift, is an exception to this.

- Inside the wind farm, an SOV may take a very long time travelling from wind turbine to wind turbine to drop off a large number of technician teams and equipment. Some SOVs are outfitted with daughter vessels (often fast cruise boats of 7–15 m) that can be launched by the davit crane on the vessel to address this issue and meet safety criteria for emergency evacuations. The daughter craft, on the other hand, mostly functions in extremely favorable conditions, ideally when the significant wave height is less than 1.2 m. Occasionally the daughter craft will have to operate in case of emergencies to provide fast transit.

2.1.4 *Helicopters*

For winds up to 20 m/s, helicopters can offer access through the helideck of the substation as well as the hoisting platform on top of the wind turbine nacelle. Due to safety concerns with helicopter access, regulations for ditching (a safe landing on water during an emergency) have been defined, which also include a maximum sea state restriction for helicopter transportation. Helicopters can significantly reduce travel time compared to CTVs, but they are expensive (typically costing between 100 and 200 euros per minute, depending on the size of the helicopter) and only have a small payload capacity (usually 3 to 6 technicians and a small amount of small spare parts and tools of usually less than 100 kg each). The amount of helicopter waiting time in an offshore wind farm while technicians are working inside a nacelle is very constrained (usually less than 30 minutes), unless they can make a temporary landing on a fixed landing platform nearby. In general, the helicopters that maintain offshore wind farms leave the wind farm after their work. As a result, after transferring the technicians, helicopters return to the heliport before returning to the wind farm to pick up technicians. This necessitates two round-trips for a helicopter transfer and doubles the expense. When helicopters are used on their own, no emergency backup evacuation is possible until the helicopter returns.

Figure 11: Offshore wind helicopter access.

2.1.5 *Autonomous vessels*

Offshore wind industry already started using autonomous vessels in many O&M phases, but the main obstacles to their autonomous use are a lack of standardized regulations, problems with quality assurance, and their dependency on manual deployment and retrieval. It is acknowledged that by further automating these technologies, to the point where they can run entirely on their own, greater cost savings and enhanced safety may be achieved. Despite the technological challenges and legislative hurdles to fully exploit such systems, there are substantial efforts to develop these technologies.

Figure 12: Perceptual robotics UAV performing visual inspection.

Figure 13: XOCEAN's XO-450 unmanned surface vessel (USV) performing seabed survey.

Figure 14: A consortium comprising of the R&D UK Centre of EDF Energy, UTEC, an Acteon company, and Partrac Ltd completed an offshore trial designed to assess the performance of a commercial UUV (UUV) for mapping seabed bathymetry.

- Unmanned aerial vessels (UAVs): The majority of unmanned inspections conducted by UAVs use visual-based techniques. There are, however, a relatively small number of UAVs that can do close-contact Non-Destructive Testing (NDT) inspections. Although doing a visual inspection of an OWT is simpler for a UAV, performing maintenance or repair work using a single UAV proves to be a very challenging process due to the lack of additional hands or tools when compared to manual operation by human operators. For instance, a UAV that is unable to transport a variety of tools or heavy machinery will not be able to carry out maintenance or repair operations.
- Unmanned surface vessels: Unmanned Surface Vehicles (USVs), which are primarily utilized for visual inspection tasks like subsea surveys, have already been deployed for

unmanned operations of the OWT. USVs are also used to perform seabed surveys for potential OWT farms and to keep an eye on the scouring of piling foundations.

- Unmanned underwater vessels: Unmanned inspections of underwater OWT structures are currently carried out by unmanned underwater vessels (UUVs). A UUV might be capable of performing maintenance and repair tasks on OWT undersea structures or subsea cables, but it would still need a nearby station or vessel to charge its batteries, to attach to, or relay inspection and maintenance data.

2.1.6 *Virtual reality (VR)*

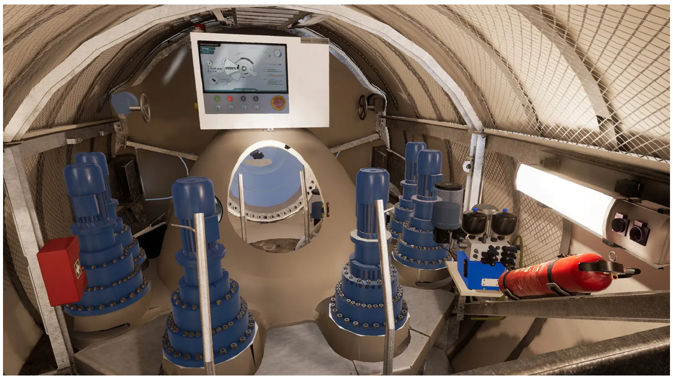

Figure 15: Remote wind turbine inspections using VR technology, source: VR Lab.

The logistics of training in the harsh offshore environments where the wind farms are located, as well as the physical space restriction of only allowing three people to be present at a time inside the nacelle of the WTG, proves expensive. Multiple users can access and acquire in-depth information on wind turbine systems through virtual reality (VR), which includes real 3D Sounds recorded from the sites. This is possible without actually travelling to the locations. The energy production is hampered when training with a turbine, thus it is advisable to train a fault or breakdown in virtual reality. The complexity of the training can be changed in the VR simulation by adjusting scenarios, weather conditions, and wind speeds.

2.2 Access systems

The need for a wind farm with high availability has facilitated the growth of gangway systems that can be added to improve accessibility and general safety. These systems offer safer and more comfortable access directly to the TP platform at an elevation from sea level of roughly 15 to 20 meters. Due to the limited accessibility that access vessels can provide, the impact of safety-related risks, and the effect on humans due to motion-induced fatigue, increases. To achieve this, access systems are created to avoid relative motions between the vessel while accessing the wind turbine. Please refer to chapter 3 for more information.

2.2.1 *Compact gangway systems*

Compact gangway systems can be put on the wind turbine foundation structure or the foredeck of the ship to correct motions. For each system, there are different requirements for the boat landing and vessel characteristics, such as length (active or passive).

2.2.2 *Motion compensated gangway systems*

The two motion compensating techniques are active and passive. To reduce relative motions, active motion compensation employs sensors and control mechanisms. A mechanical link that passively adjusts itself achieves passive compensation. The market for providing access to offshore wind farms using motion-compensated gangways is still developing. In addition to motion-compensated gangways, other systems that can be installed aboard ships to transport technicians to the TP platform exist. Active motion compensated gangways make up the majority of the systems giving personnel direct access to the TP's work platform. A growing number of them are also able to lift heavier objects, typically up to 1000 kg.

2.2.3 *Motion compensated cranes*

Transferring employees and freight to the offshore installations is crucial. Transporting equipment and parts to wind turbines and substations is generally necessary for maintenance purposes (individually, in crates or in small containers). There are various methods to transport loads depending on their weight. The lightweight equipment and spare components can be lifted by helicopters or carried by technicians. Loads up to one ton can normally be lifted from the vessel by the davit crane on the platform of the transition piece. Additionally, as was already indicated, some motion-compensated gangways can also transport spare parts (generally below 1 ton). Transfer of goods in the offshore environment, however, can become a challenging issue as the cargo weight or the platform's height increases. In this context, the industry has introduced to motion compensated cranes. The majority of the time, they are mounted on SOVs and can position the load on the drop zone even if the vessel is moving or pitching because of waves and current. Some of them can also transfer technicians. Despite being relatively new to the market, motion compensated cranes are anticipated to play a bigger role in the future, especially as individual turbines get bigger.

2.3 Accessing Floating Offshore Wind Turbines

There is considerable interest in Floating Offshore Wind Turbines (FOWTs) in order to take advantage of stronger and more stable winds and to get beyond the limitation associated with using seabed-fixed foundations. As floating wind farms can be placed further away from the shore, there will be more logistical and operational challenges that will require considerable and lengthy maintenance. Technically speaking, risks and the accompanying mitigation strategies must be taken into account. The chosen access plan will be influenced financially by the cost of operation as well as the cost of lost revenue from the times the floating system(s) are not producing energy. With reference to Figure 16, few different possible strategies could be considered for accessing and carrying out maintenance activities, namely:

- Floating to floating: This situation involves offshore overhaul, which means that the replacement will be completed totally on site. Using cranage, a heavy lift vessel working at the wind farm site can carry parts directly to and from the FOWT (floating offshore wind turbine). In order to design vessels and systems capable of carrying out the replacement operations in a floating-to-floating configuration, the maritime sector must rapidly evolve.
- Tow-to-port: In this scenario, maintenance will be carried out onshore, therefore offsite, after having carried out a reversed-installation operation and hauled the turbine unit to the harbor, for the onshore overhaul (dry-dock or inshore). The FOWT is repaired with

cranage in onshore-like conditions using easily accessible, relatively inexpensive lifting systems. This process may be difficult, lengthy, and expensive in terms of operations and downtime, and it also necessitates Major Components Replacement (MCR) capabilities at the O&M sites (which is not always the case).

- Tow-to-shore: This is a hybrid approach that combines the tow-to-port strategy's reverse installation process with the unit being hauled closer to shore, where a fixed jack-up vessel is installed (i.e. vessel with fixed support structures). This approach can often be taken into account when the project's characteristics (geography, floater design), as well as potential synergies with other bottom-fixed assets, are favorable. Due to the renting of the jack-up vessel instead of an onshore crane, this technique may be more expensive.
- Self hoisting cranes: With this approach, significant components are to be replaced by new self-hosting or climbing cranes without the need for costly tow-to-port operations or the use of vessels other than support barge-type (or similar) vessels at the site. As technology advances and new businesses enter the market, discussions about the use of various crane technology/vessel combinations have begun. This raises questions regarding lifting capability, time spent operating at sea, responsibilities of Original Equipment Manufacturers (OEMs), etc.

Figure 16: Schematic of different access strategies for floating offshore wind turbines.

3 Commercially available access vessels and systems

This section aims at giving an overview of commercially available access solutions. Summary tables with complementary specifications on the various access systems are available in appendix.

3.1 Acknowledgments

This is the 5^{th} edition of TNO's Offshore Wind Access Report. The previous edition [7] was published in 2020 (click here to download), and TNO intends to update this report on an annual basis. TNO would like to thank the following companies for providing essential inputs and up to date information to this report (in alphabetical order):

- Ampelmann B.V.
- Barge Master B.V.
- Eagle Access B.V.
- SMST Designers & Constructors B.V.
- Ulmatec AMC
- Uptime International A.S.
- Z Bridge B.V.

3.2 Ampelmann B.V. Gangways

Ampelmann manufactures five types of gangways, the L, A, E, N and W types, in which all critical components are installed redundantly to ensure constant and safe operation:

- Ampelmann L-Type: The L-type is the smallest Ampelmann system, suitable for fast crew vessels without Dynamic Positioning (DP), though specified for vessels with a minimal length of 30 m. It is a plug and play, fully electric system, allowing fast mobilization. Active compensation is used during landing and passive compensation during transfer.
- Ampelmann A-Type: The A-type is the first system to provide active compensation by means of the hexapod system (since 2008), using a six hydraulic cylinders system inspired by the Stewart platform. Ampelmann A-Type series currently has five models: A, AEP, A100, A400 and A-type 3.0, which vary in size, maximum operational sea states, capabilities of cargo transfer and energy sources. It is the most commonly used Ampelmann type in the offshore wind sector, especially A and AEP models.
  - The A and AEP can only transfer personnel, while A100 and A400 are also suitable for transferring small-sized cargo.
  - The AEP provides an enhanced performance with extended maximum operational sea state.

  - The A400 offers the benefit of a wider gangway of 1.2m.
  - The A100 has a basket at the tip of the gangway which can take loads up to 100 kg and the A400 allows to use electric trolleys through the elevator and gangway to transfer load up to 400 kg in a stepless approach.
  - The A-type 3.0 uses electric cylinders instead of hydraulic ones, and can be directly powered by the electricity supply from the vessel. The electric actuation allows for power regeneration during parts of the compensation cycle, and a balanced heave compensation technology is integrated which both reduces the power consumption. Finally, the electric model also saves weight and deck space.

- Ampelmann E-type: The E-type is based on the same technology as the A-type, although it is 1.5 times larger. Because of its increased size, the system is capable of compensating higher sea states. Ampelmann E-Type series has three models: E, E1000, E5000. The model E1000, E5000, can also transfer cargo in crane configuration. The transformation from the gangway to crane configuration (and vice versa) takes less than one minute.
- Ampelmann N-Type: The N-type has been designed for operation in extreme cold regions with temperatures down to -40 ºC, ice and snow. The N-type improves safety and efficiency of operation through active motion compensation fully controlled from the vessel and flexibility in platform landing locations and directions.
- Ampelmann W-Type: The W-type is a built-to-order system that is fully integrated into an SOV. The system is electrically powered to reduce carbon footprint. Instead of using the hexapod platform, the SOV-type has adopted the elevator tower concept for the stepless transfer of personnel from the vessel warehouse to the gangway. With the gangway moving up and down along the tower and rotating around the base, the system provides 3-D motion compensation through gangway luffing, slewing and telescoping.

Ampelmann is currently developping a new type of gangway, the F-type to fill the gap between the L and A types for lower sea states locations or on larger installation vessels with lesser needs for motion compensation. The first unit is expected to be ready for end of 2024.

Finally, Amplemann also worked with Damen in a joint-venture to develop a purpose built gangway system, the S-type, on Damen's purpose build vessel "Aqua Helix".

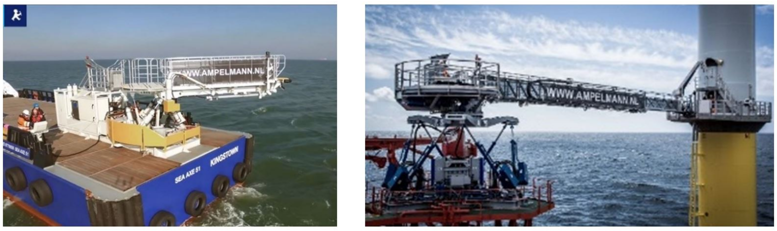

Figure 17: Ampelmann gangways - L-type and A-type (from left to right)

Figure 18: Ampelmann gangways - E-type, N-type and W-type (from left to right)

Table 2: Ampelmann B.V. Gangways

	L-Type	A-Type	E-Type	N-Type	W-Type
Max length gangway [m]	13	25	30 (E1000) 31 (E5000)	32	28 (28m) 32 (32m)
Max working angle [deg]	±17	±17	-17 +65	±15	±17
Gangway width [m]	0.6	0.6	0.6	0.8	1.2
Max load [kg]	150	250 (hydr) 400 (elec)	1000 (E1000) 5000 (E5000)	450	2000
No. of systems built [-]	8	43 (hydr) 2 (elec)	15 (E1000) 1 (E5000)	1	0 5 ordered
No. transfers [-]	>200,000	>3,000,000	>1,500,000	> 20,000	0

3.3 Barge Master B.V. Gangways

Barge Master's gangway was introduced in 2015. The gangway can be installed as a basic system mounted directly on the deck of a vessel, on a fixed pedestal of any height. The gangway can also be equipped with an adjustable pedestal with integrated elevator to facilitate variations in landing height or tidal range. The system can additionally be used for trolley transfer for 800 kg cargo and be fitted with a module that can provide a hoisting capacity up to 2000 kg.

Since the last edition of the report, several additional features on the Barge Master motion compensated gangway have been developed:

- A tip ladder is provided for the gangway. This ladder adds an extra 2 meters to the operational range of the gangway, but more importantly makes it possible to land in hover mode over an existing structure, where a normal push landing is not possible.
- Together with Van Halteren Technologies (previously known as Bosch Rexroth), Barge Master has launched the autonomous landing function. The purpose of autonomous landing is to improve safety and efficiency, and to eliminate human error. This function can be introduced on all the new build gangways, and also be retrofitted to existing systems. The Barge Master has a small foot print and low weight. These features make it a versatile unit to be rented for projects. Barge Master is developing the next generation gangway with a length of 30 m.
- The system can run on biodegradable oil.

Figure 19: Barge Master gangway on height adjustable pedestal with elevator

Table 3: Barge Master B.V. Gangways

	Basic	Height adjustable with elevator	Height adjustable with elevator XL
Max length gangway [m]	25.1	25.1	30.1
Max working angle [deg]	-23 +23	-23 +23	-23 +23
Gangway width [m]	0.9	0.9	1.2
Max load [kg]	1000	1000	2000
No. of systems built [-]	3 +3 under construction	1 + 2 under construction	0
No. transfers[-]	>70000	>70000	-

3.4 Barge Master B.V. Motion compensated crane

The Barge Master BM-T40 is a 3D motion compensated pedestal crane. Instead of compensating the motion of the jib, BM-T40 keeps the entire crane still by actively compensating the motion at the pedestal. Besides the suitability of lifting loads, the T40 is manriding certified for safe personnel transfer. This crane model is currently installed on the Wagenborg vessels Kasteelborg and Kroonborg amongst others.

Figure 20: Barge Master T40

Table 4: Barge Master B.V. Motion compensated crane

	BM-T40
Ability to transfer personnel [-]	Yes
personnel [-]	
Max safe working load for cargo [ton]	at 10m radius: 15 ton (sea state 4)/ 20 ton (sea state 1) at 20m radius: 5 ton (sea state 4)/ 8 ton (sea state 1)
Max crane lifting height [m]	35
Compensation DOFs [m]	3
Wave period limits [s]	4-18
Max wind speed [m/s]	-

3.5 Eagle Access B.V. Gangway and Motion compensated crane

EAGLE-ACCESS is a fully electric-powered system, supported by a back-up battery. The lighter weight of the system, which accounts for 27 ton, also leads to less energy consumption (75kW). A motion compensated tip is used for transferring 1-4 technicians in a safe enclosed cabin or a cargo up to 1 ton directly from the deck to the offshore platform. Due to its specific design, it allows 270 degree of slewing, and the horizontal reach of 27m from the centre pedestal and vertical reach of 25m from the deck level. The system can be fully integrated or delivered as stand-alone. The system has already been demonstrated on land and has been set out for sea trials in early 2021. The system is also capable of delivering cargo at night to the TP platforms due to the obstacle measuring systems on the hook assembly.

Figure 21: EAGLE ACCESS with an enclosed cabin for technician transfer (left), and used to hoist and deliver cargo (right)

Table 5: Eagle Access B.V. Gangway

	W2W
Max length gangway [m]	27
Max working angle [deg]	-
Gangway width [m]	-
Max load [kg]	1000
No. of systems built [-]	1
No. of transfers [-]	500

3.6 SMST Designers & Constructors B.V. gangways

SMST provides a range of gangways for safe, easy and efficient offshore transfer of personnel and cargo. There are three versions (M, L and XL) of the SMST gangway, Telescopic Access Bridge (TAB) varying in length from 4 up to 58m. The bridges can be actively or passively motion compensated and are available for purchase and specific types are also for rent.

The modular setup of the SMST gangway systems enables setting up a TAB that meets all project-specific requirements. Working on various heights is possible by means of stacking modules and a Height Adjustment System that travels vertically along a rail system, enabling connections with large differences in landing heights and extreme heights (as shown in figure 22.). The modularity of the gangways ensures fast and easy mobilization. In addition, the TAB-L has also been offered as an integrated design with the new-built SOV's, together with an Access and Cargo tower including elevator.

For cargo handling the gangways can be equipped with a lifting winch on the bridge tip, a cargo travel system under the bridge and/or a cargo transporter. The cargo handling options are also available for the rental setups.

Figure 22: SMST TAB: M series, L series with Height Adjustment System and L series together with an Access & Cargo Tower (courtesy of SMST)

Table 6: SMST Designers & Constructors B.V. Gangway

	TAB M	TAB L	TAB XL
Max length gangway [m]	21	25-31	43-58
Max working angle [deg]	-20 +25	-20 +25	-23 +27
Gangway width [m]	0.6	0.9-1.2	1.5
Max load [kg]	300	1000/6000	10000
No. of systems built [-]	12 +2 under construction	15 + 12 under construction	5
No. transfers[-]	-	-	-

3.7 SMST Designers & Constructors B.V. motion compensated cranes

SMST offers three sizes of the 3D motion compensated cranes (M, L and XL) and are designed to be mounted on Service Operation Vessel (SOV) and Walk-to-Work vessels. The 3D crane can safely transfer equipment to an offshore structure, even in harsh conditions. The vessel motions are compensated in all directions by means of the 3D motion compensated knuckle.

The modular setup of the crane allows the 3D knuckle to be easily exchanged with a subsea knuckle for deep-water operations.

Ten systems have been installed on vessels: two M-size with capacity of 1 ton on the vessel Edda Passat and Edda Mistral; one M-size with capacity of 2 ton on the vessel Rem Energy; three M-size with capacity of 3 ton on the vessel Bibby Wavemaster Horizon, Esvagt Froude and TSS Pioneer; two L-size with capacity of 5 ton on VOS Stone and VOS Start, and two L-size with capacity of 6 ton on Acta Auriga and Acta Centaurus.

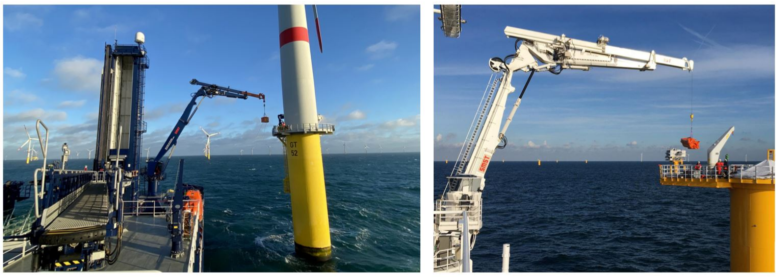

Figure 23: SMST motion compensated crane in operation (Courtesy of SMST)

Table 7: SMST Designers & Constructors B.V. Motion compensated cranes

	M	L	XL
Ability to transfer personnel [-]	Yes -	Yes -	Yes -
Max safe working load for cargo [ton]	3-25	5-50	20-150
Max crane lifting height [m]	-	-	-
Compensation DOFs [m]	3	3	3
Wave period limits [s]	-	-	-
Max wind speed [m/s]	25	25	25

3.8 Ulmatec AMC Gangway

The Ulmatec AMC gangway system is an active motion compensated gangway. It is hydraulically powered and can slide vertically on a rotating tower. Personal and goods are brought from deck to gangway level with an internal elevator.

Ulmatec has a team of engineers dedicated to ensuring the gangway system fits best the need of their customers and the typical specifications provided in this report can be adapted to fit specific needs.

Figure 24: Ulmatec AMC

Table 8: Ulmatec AMC Gangway

	AMC
Max length gangway [m]	32
Max working angle [deg]	± 22
Gangway width [m]	1.2
Max load [kg]	3(AHC crane) + 1 (pallet)
No. of systems built [-]	2
No. of transfers [-]	-

3.9 Uptime International A.S. Gangways

Uptime's active motion compensated logistics systems (either 23.4m or 30m) have been on the market since 2012 and they have an extensive track record. The 23.4 have been delivered for over 10 years, with both bumper mode and cone type landing. Selection of landing mode is subject to duration of the operation, and suitability of geographical location and/or market.

The next generation 30m (both Type 1 and 2) is the world's first autonomous gangway with artificial intelligence which has been proven in the European market since 2019. Designed with autonomous landing function for increased safety , in addition to integration of operator position located next to the DP operator in wheelhouse. Furthermore, the 30m can be equipped with an integrated crane function with lifting capacity up to 6 tons static and 3 tons dynamic(3D). "Island Clipper" installation is a reference for 30m Type 1(DNV ST-0358), while as the "Windea Jules Verne" installation is a reference for 30m Type2(DNV ST-0358). The delivery program for 2022-2024 has just started with a large roll-out of new-builds for both tender chartered vessels as well as speculation builds.

The world's largest (one-off) active motion compensated logistics system 57.5m, installed on "Edda Fortis" (former "Hyundai Ulsan 2652") Accommodation Vessel which recently has been announced with a new owner, entering market 2025.

Uptime also delivers passive motion compensated logistics systems, ranging from 40m to approx. 60m most commonly used for 24/7 connection in the offshore energy sector. With approx. 100 references dating back to 1979 up until the most recent delivery to BP's Tortue project in Senegal/ Mauritania consisting of two 46.5m Ex-approved systems (DNV-ST-0358).

Most of the gangways produced by Uptime International are being sold, but the company has also built up a rental pool of 5-10 assets in the recent years.

Figure 25: Uptime 23.4m, 30m, 57.5m (from left to right)

Table 9: Uptime International A.S. Motion compensated for personnel transfer gangways

	23.4m	30m	40m	42.5m	46.5m	57.5m
Max length gangway [m]	23.4	30	40	42.5	46.5	57
Max working angle [deg]	-10 +15	$\pm$ 20	$\pm$ 20	-16 +24	-16 +24	-16 +24
Gangway width [m]	1.2	1.2	0.9	1.2	1.2	1.5
Max load [kg]	700	3000	1000	3600	3600	-
No. of systems built [-]	26	6	-	52	34	1
No. of transfers [-]	1,000,000	500	-	1,000,000	1,000,000	-

3.10 Uptime International A.S. Motion compensated cranes

Uptime also offers standalone 3D motion compensated cranes as part of a logistics system delivery, branded as Uptime by Motus. MMC240, MMC400 and MMC 500 depending on lifting capacity and reach. The crane design is based on a standard knuckle boom crane and optimized for 3D compensation with a telescopic elbow derrick with integrated winch. The 3D compensation is performed by use of 3 degrees of freedom winch, telescopic derrick and slewing. The robust crane has a low weight, and can be supplied with options such as personnel lift and heavy cargo lift.

Table 10: Uptime International A.S. Motion compensated cranes

	M3D 240	M3D 240 / M3D 400	
Ability to transfer personnel [-]	Yes	Yes	Yes
Max safe working load for cargo [ton]	5-3D 10-onboard	7-3D 12-onboard 20-onboard - separate winch	-
Max crane lifting height [m]	17-3D 29-onboard	17-3D 29-onboard	
Compensation DOFs [m]	3	3	-
Wave period limits [s]	-	-	-
Max wind speed [m/s]	25	25	25

3.11 Z Bridge B.V. Gangway

Z bridge has developed two gangway systems, the first is the Zbridge W2W by ZTechnologies, operational since 2019. It is a patented motion compensated gangway system that eliminates the rotative (pitch & roll) movement of the mast. The system's elevator provides direct access for 4 people or 500kg cargo to the offshore platform, but the capacity can be upgraded to allow 8 people or up to 1000kg cargo. The landing height is adjustable from 2.5m up to 23m.

The second is the Zbridge B2W, a newly built system based on the patented motion compensated pedestal of the W2W system. It is provided with an elevator for transporting 1-6 personnel or cargo up to 1000kg. The elevator can be upgraded to lift up to 3000kg. The system can also be used as a 3D motion compensated crane to hoist up to 3 ton of cargo from the deck to the platform. With its relatively low weight, the system can be installed on a CTV, which is able to transfer from vessel deck to the platform while the CTV thrusts against the boat landing area. Since the previous issue of the Offshore Access Report, the system has been tested and is actively deployed on various wind projects and the combination of crane and transfer capabilities showed that the system is highly efficient in operations where materials and equipment have to be installed on the TP- or wind turbine platform. Specially in pulling operations for cable projects and/or the installation of power packs for commissioning work, the system proved to be very efficient.

Figure 26: Zbridge W2W with system's elevator (left), Zbridge B2W used as a crane (right)

Table 11: Z Bridge B.V. Gangways

	W2W	B2W
Max length gangway [m]	24	27
Max working angle [deg]	$\pm$ 15	-55 +10
Gangway width [m]	1.2	1.2
Max load [kg]	1000	1000
No. of systems built [-]	1	6
No. of transfers [-]	>1,200	>3,500

3.12 Royal IHC B.V. Gangway (Last updated in 2020)

Royal IHC has developed two motion compensated gangway system, the AMC38 system from 2010 (first delivery in 2017) and more recently the Sea-Link® system. With its 38m length, the AMC 38 is one of the longest active motion compensated gangways on the market. Luffing, slewing and telescoping motions are actively compensated. System control modes allow the gangway to be deployed in a passive mode (with a shock absorber in the landing cone, free floating) or fully active compensated.

The Sea-Link® is a compact gangway system specifically designed for SOVs. The introduction of the patented Inter-mediate Platform on the gangway is a notable feature of this system that can significantly reduce the telescoping motion and improve safety during technician transfer.

Sea-Link®, along with an autonomous SOV, IHC Dynamic Positioning system, Path Planner and a digital twin, is a part of the integrated digital environment being developed by Royal IHC to enable autonomous operations and optimal performance of the entire system.

Table 12: Royal IHC B.V. Gangways

	AMC-38	Sea-Link	TGS
Max length gangway [m]	38	30	45
Max working angle [deg]	-20 + 25	$\pm$ 25	$\pm$ 25
Gangway width [m]	1.2	0.9-1.2	1.2
Max load [kg]	1000	1000	-
No. of systems built [-]	1	0	0
No. of transfers [-]	>1,000	-	-

3.13 Kenz Figee Group B.V. Gangway (Last updated in 2020)

The Kenz Figee Group has built two types of 3D active motion compensated gangways. The first systems (EH-15-25/1800) were developed for the POSH Endeavour and the POSH Enterprise. During landing the gangway is actively motion compensated. After connection and during personnel transfer, the system is set to passive compensation.

The second gangway system (EH 16-26/1800) has been installed on the Wilson Arctic (formerly known as Notus Express) to carry out bolt tightening work on transition pieces in Hornsea 1 wind farm during the construction phase, and also the commissioning work in Borssele II wind farm. It is equipped with active motion compensation. To access offshore wind turbines, the gangway is equipped with a bumper docking system. The gangway is also provided with a hook attachment using the same 3D motion compensation system to safely hoist equipment to the platform.

Table 13: Kenz Figee Group B.V. Gangways

	EH 15-25/1800	EH 16-26/1800
Max length gangway [m]	24.6	27.1
Max working angle [deg]	± 15	± 18 (personnel) [-20; +50] (cargo)
Gangway width [m]	0.8	1.2
Max load [kg]	300	500 (personnel) 1000 (cargo)
No. of systems built [-]	2	1
No. of transfers [-]	>20,000	>10,000

3.14 Mac Gregor Norway AS Motion compensated cranes (Last updated in 2020)

Ulstein and TTS have collaborated to provide the TTS Colibri series of 3D motion compensated cranes to the offshore industry. The Colibri motion compensation system is a stand-alone add-on device to a standard offshore crane. It can be mounted on the tip of a standard crane as a new-build option or retrofit. In addition, Colibri uses "ground breaking anti-sway technology" to mitigate wind induced motions acting directly on the load. The cranes come in a range of 3 different sizes: 1 mT, 3 mT and 7 mT. The first system (1 mT version) has been installed on the newbuilt offshore wind SOV Wind of Change for Louis Dreyfus Armateurs. A second crane (3 mT version) was delivered to its sister-ship Wind of Hope of LDA in 2021. In addition, four more Colibri 3D motion compensated crane will be installed on the new vessels under construction for Edda Wind (Østensjø), with two 3 mT versions and two 5 mT versions.

Table 14: Mac Gregor Norway AS Motion compensated crane

	Colibri
Ability to transfer personnel [-]	Yes
Max safe working load for cargo [ton]	1, 3 or 7 ton at H=2.5m
Max crane lifting height [m]	40
Compensation DOFs [m]	3
Wave period limits [s]	4
Max wind speed [m/s]	24

3.15 Van Aalst Group B.V. Gangway (Last updated in 2020)

Van Aalst developed three types of motion compensated gangways, the Safeway Seagull, operational since 2017, the Safeway Gannet, and the Safeway Ofsprey.

The Safeway Seagull is developed for retrofitting on existing vessels. It comes with an integrated vertical elevation feature with 10m range, allowing level offshore access at various sites. It features roll compensation at the base of the mast and a moving counterweight at the back of the gangway to improve the heave compensation. The gangway can land on the offshore structure in hover mode, with the tip going over the obstacles without physical connection. To improve the safety and comfort under all conditions, the gangway is fully enclosed. For cargo transfer, the system is equipped with 1 ton 3D lifting at the gangway tip.

The Safeway Gannet is a hull integrated gangway system, designed especially for the new-built SOV's. The system also provides hover mode, roll compensation and counterweight features. Furthermore, with 1.2m gangway width, Safeway Gannet offers a stepless transfer with trolley operations from the vessel to the offshore structure.

The Safeway Osprey is a self-sustained system which can be relocated to any location on deck to meet specific project requirements or deck arrangements. Safeway Osprey does not have the roll compensation feature form the Safeway Seagull type. However, it has an extended gangway length (22m – 32m), wide gangway (1.2m) and large vertical elevation range (12m). Two Safeway Osprey systems have been produced: One is a hull integrated version for the Alfa Lift 1 and the other is a standalone deck type for the DEME Orion.

Table 15: Van Aalst Group B.V. Gangways

	Safeway Seagull	Safeway Albatross	Safeway Osprey
Max length gangway [m]	28-30	30-32	32
Max working angle[deg]	$\pm$ 15	$\pm$ 15	$\pm$ 15
Gangway width [m]	1	1.2	1.2
Max load [kg]	1000	2000	1000
No. of systems built [-]	6 3 under construction	0	0 2 under construction
No. of transfers [-]	-	-	-

4 O&M modelling

This chapter explains the added value of O&M modelling when assessing the impact of various access vessels and systems, and presents of a case study by using TNO's in-house developed O&M Planner simulation tool.

4.1 TNO O&M Planner

TNO O&M Planner was developed based on TNO wind group's long expertise in O&M cost calculation and simulation tool: ECN O&M Tool (excel based tool), which has been the industry standard since 2005, and later ECN O&M Calculator. A MATLAB based software was its upgrade from 2011. The softwareintends to model increasingly complex features in O&M planning for large and upcoming OWFs, such as floating turbines and clustering of maintenance activities. As a consequence, TNO has been developing O&M Planner and using the software for long term O&M strategy evaluation studies since 2020.

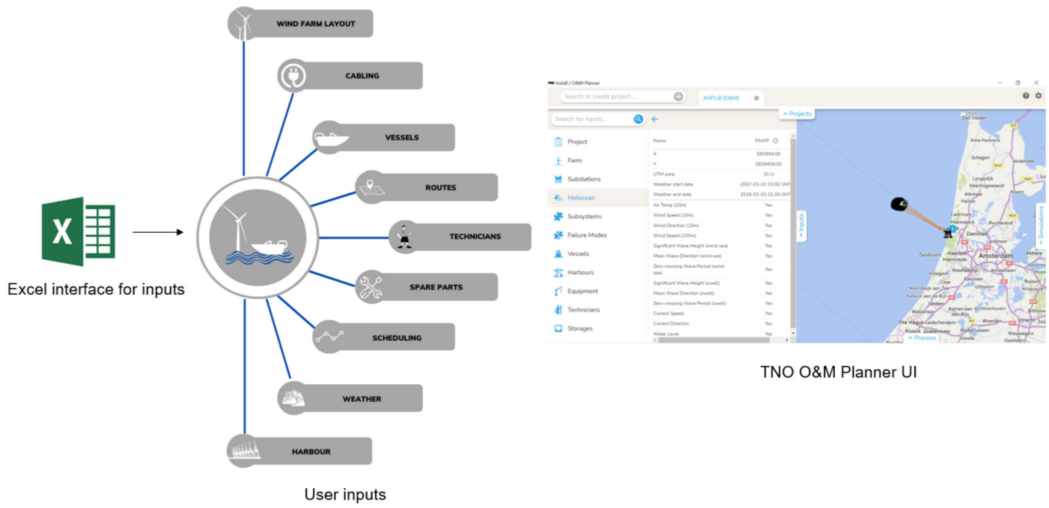

Figure 27: TNO O&M Planner framework

TNO O&M Planner is built on a discrete event based logistic simulation engine UWiSE (Unified Wind farm Simulation Environment), developed by TNO since 2017. The software enables modellers to run simulations over multiple years, to calculate O&M costs, wind farm availability and energy production, while accounting for uncertainties based on weather input and component failure rates. The tool shows the impact on O&M key performance indicators (KPIs) of deploying various types and numbers of transport equipment such as vessels, helicopters and barges, each with their own weather limits of operation. O&M Planner is currently developed to also accommodate future offshore wind use cases, such as (but not limited to) floating wind farms, wind farm clustering, resource sharing, and hydrogen production. Figure 27 displays the user interface of TNO O&M Planner. More information can be found on https://uwise.tno.nl/.

The software primarily aims to:

- Help wind farm operators optimize O&M choices between various transport modes, equipment, personnel and stock management options in terms of standard KPIs like farm availability and repair costs.
- Perform scenario studies for an O&M project by varying the available resources (e.g., three crew transfer vessels vs. one service operation vessel).
- Provide an overview of maintenance actions planned and executed, the delays encountered (due to weather, personnel or vessel) and their associated costs.
- Provide insight into the causes of wind farm downtime per component failure mode and execution of scheduled maintenance activities.
- Evaluate the impact of innovative concepts (e.g., large component replacements with motion compensated cranes) on O&M KPIs

4.2 Case study

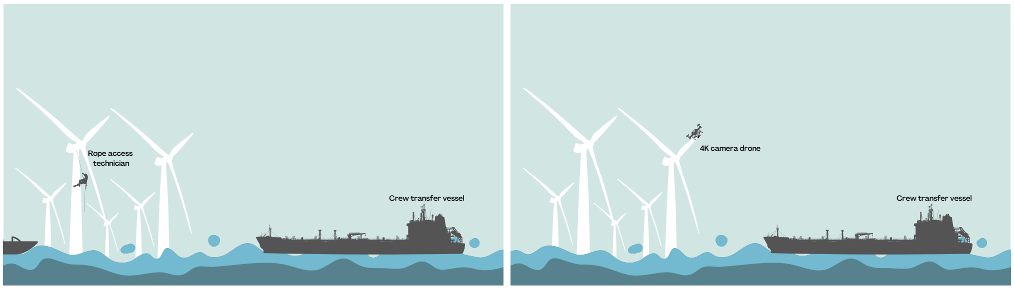

Figure 28: Schematic of the inspection scenarios showing scenario 1 consisting of rope access (left) and drone inspection (right)

In order to illustrate the framework of O&M modelling using different access vessels strategy, a periodical inspection on sixty 2MW wind turbines of the Amalia Wind park is considered as reference for the case study. The metocean weather data used correspond to an offshore local on 10km north of the Amalia Wind park Site . It should be noted that for this case study, the weather operating limits for simulation input include only thresholds on wind speed and significant wave height.

In Scenario 1, the inspection will be carried rope access technicians assisted by CTV's, whereas in Scenario 2 drones will be used that will be controlled by RC pilots onboard the CTV's. The data associated with the scenarios and the KPIs are listed down in Table 16

The results deduced from the O&M Planner simultaions suggest that Scenario 2 takes longer, viz. 8 days, to finish the visual inspection in comparison to Scenario 1 taking 7 days to complete. This is because, for the drone operation, the maximum allowable measured wind speed at 100m was set to ≤ 10m/s. This value ensures safety for drone operations. Metocean data when not complied with the set criterion resulted in the delay. Moreover, TNO O&M Planner also takes

Table 16: Scenario characteristics with key performance indicators

	Scenario 1	Scenario 2
Activity	Visual inspection	
Frequency (Turbines/day)	10	12
Technician cost (Euros/day)	1200	700
Vessel cost (Euros/day)	4000	4000
Duration (days)	**7**	**8**
Total O&M costs (Euros)	**36400**	**37600**

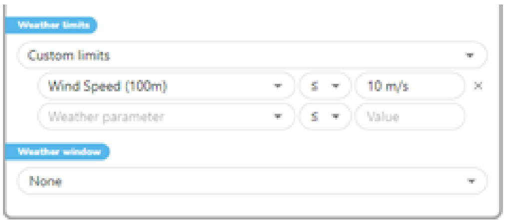

Figure 29: Custom weather limit set in TNO O&M Planner for drone operation

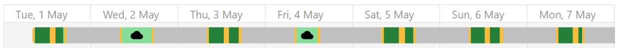

Figure 30: Detailed breakdown of the O&M activity indicating weather delay (cloud icon)

into account the weather delays based on the metocean data that would aid during the planning of O&M activity. As a consequence, the simulated O&M activity for Scenario 1 was completed in 7 days in May since the activity suffered from weather delays.

Finally, it should be noted that the results are purely indicative specifically for the reference wind farm that was chosen including distance from port, relevant metocean conditions and other inputs assumptions. Hence, generic conclusions should not be drawn and for each wind farm, a dedicated model should be developed.

5 Conclusions & future outlook

The main objective of this report was to present an overview of the current and future access solutions for offshore wind O&M activities. A wide variety of CTVs are being employed primarily for offshore wind O&M, giving access up to sea states of H_s of 1.5 to 2 m, according to the review performed. Additionally, a variety of access systems that improve the accessibility and safety of CTVs have hit the market and are highlighted in this report. Access through CTVs is relevant for near-shore wind farms, which are typically closer to the shore than 70km. Beyond this distance, offshore accommodation is inevitable and the current trend shows the potential of SOVs and motion compensated gangways as the access methods. The quick response time and nearly limitless accessibility of helicopter support might be highly advantageous for offshore applications. Moreover, innovative autonomous concepts that include a variety of access systems are included in this report. Lastly, a case study was used to illustrate how TNO O&M Planner tool can be used to evaluate the impact of different ways of access on the performance of the wind farm.

TNO will follow the developments of offshore wind access vessels and systems and intends to update this report every year.

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Appendix: Detailed offshore access systems specifications

Gangways - 1 of 2 - Updated 2022

	Ampelmann L-Type	Ampelmann A-Type	Ampelmann E-Type	Ampelmann N-Type	Ampelmann W-Type	Barge Master Basic	Barge Master Height adjus. + elev.	Barge Master Height adjust. + elev. XL	Eagle Access
Min length gangway [m]	8	16	21 (E1000) 22 (E5000)	23	17 (28m) 21 (32m)	14.9	14.9	19.9	-
Max length gangway [m]	13	25	30 (E1000) 31 (E5000)	32	28 (28m) 32 (32m)	25.1	25.1	30.1	27
Max working angle [deg]	$\pm$17	$\pm$17	-17 +65	$\pm$15	$\pm$17	$\pm$23	$\pm$23	$\pm$23	-
Height from deck [m]	-	5.4 (hydr) 6 (elec)	9.5 (E1000) 10.5 (E5000)	12	20-25	Any.	Any.	Any.	23
Vertical reach [m]	$\pm$3.4	12	14.9 (E1000) 35 (E5000)	15	6.3-22.9	12.4	24.4	12-29.5	25
Gangway width [m]	0.6	0.6	0.6	0.8	1.2	0.9	0.9	1.2	-
System weight [ton]	8	39 (hydr) 35 (elec)	105 (E1000) 152 (E5000)	225	85 (28m) 120 (32m)	28	28 gang. 54 elev. + ped.	35 gang. 54 elev. + ped.	27
Footprint on vessel [m^2]	2.2 x 6.6	41.8 (hydr) 36 (elec)	95	121	16	dia. 1.9m	3.3 x 3.3	3.3 x 3.3	4
Significant wave height [m]	2	3 (3.5 [AEP])	4.5	3.5	3.5	>3.5	>3.5	>3.5	4.5
Vessel length [m]	30+	55+	70+	70+	70+	-	-	-	> 60
Mobilisation time [h]	8	12 (hydr) 8 (elec)	48	60	integrated	48	168	168	8
Deployment time [s]	60	60	60	120	60	32	60	60	60
Power cons. [kW]	22	2 x 200 (hydr) 47 (elec)	2 x 400	2 x 450	80	2x200	2x200	2x300	75
Max load [kg]	150	250 (hydr) 400 (elec)	1000 (E1000) 5000 (E5000)	450	2000	1000	1000	2000	1000
No. of systems built [-]	8	43 (hydr) 2 (elec)	15 (E1000) 1 (E5000)	1	0 5 ordered	3 +3 under construction	1 + 2 under construction	0	1
No. transfers [-]	>200,000	>3,000,000	>1,500,000	> 20,000	0	>70000	>70000	-	500

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	SMST TAB M	SMST TAB L	SMST TAB XL	Ulmatec AMC	Uptime 23.4m	Uptime 30m	Uptime 40m	Uptime 42.5m	Uptime 46.5m	Uptime 57.5m	Z Bridge W2W	Z Bridge B2W
Min length gangway[m]	13	15-19	28-38	20	15.4	20	25	30.5	30.5	37	15	18
Max length gangway[m]	21	25-31	43-58	32	23.4	30	40	42.5	46.5	57	24	27
Max working angle [deg]	-20 +25	-20 +25	-23 +27	$\pm$ 22	-10 +15	$\pm$ 20	$\pm$ 20	-16 +24	-16 +24	-16 +24	$\pm$ 15	-55 +10
Height from deck [m]	Up to 30	Up to 30	Variable	Unlimited	Custom	Custom	Custom	Custom	Custom	Custom	13	7-21
Vertical reach [m]	5-40 (adjustable)	5-40 (adjustable)	46	Unlimited	7.1	19	20	20	22	26	12.5	14
Gangway width [m]	0.6	0.9-1.2	1.5	1.2	1.2	1.2	0.9	1.2	1.2	1.5	1.2	1.2
System weight [ton]	-	-	-	110 at 25m height	28	36	50	78	40	140	50	27.5
Footprint on vessel [m^2]	20ft container	various	dia. 3.2	4 x pi	10	10	15	20	20	30	15	5
Significant wave height [m]	2.5-3.5	3-4	>4	4.5	3.5	4.5	4.5	6.0	6.0	6.0	4	3
Vessel length [m]	Various	Various	Various	20 - 500	>60	>60	>60	>80	>80	>80	> 50	various
Mobilisation time [h]	24	-	-	4 weeks in new build	30	30	50	50	50	60	36	12
Deployment time [s]	150	150	-	24h on rental skid	60	60	90	180	180	180	60	60
Power cons. [kW]	55	100	86	44	320	550	300	210	230	500	50	50
Max load [kg]	300	1000/6000	10000	3 (AHC crane) 1 (pallet)	700	3000	1000	3600	3600	-	1000	1000
No. of systems built [-]	12 +2 under construction	15 + 12 under construction	5	2	26	6	-	52	34	1	1	6
No. transfers [-]	-	-	-	-	1,000,000	500	-	1,000,000	1,000,000	-	>1,200	>3,500

Motion compensated cranes - 1 of 1 - Updated 2022

	Barge Master BM-T40	Eagle Access	SMST M	SMST L	SMST XL	Uptime M3D 240	Uptime M3D 240 / M3D 400	Uptime M3D 500
Ability to transfer personnel [-]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Max safe working load for cargo [ton]	at 10m radius: 15 ton (sea state 4) 20 ton (sea state 1) at 20m radius: 5 ton (sea state 4) 8 ton (sea state 1)	1	3-25	5-50	20-150	5-3D 10-onboard	7-3D 12-onboard 20-onboard with separate winch	-
Max crane lifting height [m]	35	-	-	-	-	17-3D 29-onboard	17-3D 29-onboard	-
Max radius [m]	-	-	25	35	45	26	26	33
Compensation DOFs [m]	3	3	3	3	3	3	3	-
Significant wave height [m]	3	4.5	4.5	4.5	4.5	3	3	2.5
Wave period limits [s]	4-18	-	-	-	-	-	-	-
Max wind speed [m/s]	-	-	25	25	25	25	25	25
Foundation footprint [m]	4 by 8 m triangle (Bargemaster) 3 by 7 m triangle (HPU) 3 by 7 m triangle (Crane)	4	dia. 2.2	dia. 2.6	dia. 3.2	dia. 2.0	dia. 2.25	-
Weight [ton]	85 (Bargemaster) 34 (HPU) 35 (Crane)	-	45 with knuckle boom crane	66 with knuckle boom crane	130 with knuckle boom crane	38.8	49.8	88

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	Royal IHC AMC-38	Royal IHC Sea-Link	Royal IHC TGS	Kenz Figee EH 15-25/1800	Kenz Figee EH 16-26/1800	Van Aalst Safeway Seagull	Van Aalst Safeway Albatross	Van Aalst Safeway Osprey
Min length gangway[m]	26	20	30	14.6	17.1	18	18	22
Max length gangway [m]	38	30	45	24.6	27.1	28-30	30-32	32
Max working angle [deg]	-20 + 25	$\pm$ 25	$\pm$ 25	$\pm$ 15	$\pm$ 18 (personnel) [-20; +50] (cargo)	$\pm$ 15	$\pm$ 15	$\pm$ 15
Height from deck [m]	custom	custom and variable	custom	custom	custom	6-16	-	-
Vertical reach [m]	-	-	-	13	19	17	custom	custom
Gangway width [m]	1.2	0.9-1.2	1.2	0.8	1.2	1	1.2	1.2
System weight [ton]	-	-	-	32.1	49.3	90	75	80
Footprint on vessel [m^2]	3 x 3	3 x 3	dia. 2.8	40	12	30	30	33
Significant wave height [m]	4	>4	>4	1.5	>3	3.5	3.5	3.5
Vessel length [m]	>80	any	>80	88	83.7	>60	>60	>60
Mobilisation time [h]	-	-	-	48	48	24	-	-
Deployment time [s]	60	60	120	120	120	60	60	60
Power cons. [kW]	2 x 140	$\leq$ 2 x 225	60	200	260	75-85	75-85	30-100
Max load [kg]	1000	1000	-	300	500 (personnel) 1000 (cargo)	1000	2000	1000
No. of systems built [-]	1	0	0	2	1	6 3 under construction	0	0 2 under construction
No. of transfers [-]	>1,000	-	-	>20,000	>10,000	-	-	-

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	Mac Gregor Colibri
Ability to transfer personnel [-]	Yes
Method to transfer personnel [-]	-
Max safe working load for cargo [ton]	1 or 3 or 7 at H=2.5m
Max crane lifting height [m]	40
Max radius [m]	35
Compensation DOFs [m]	3
Significant wave height [m]	3.5
Wave period limits [s]	4
Max wind speed [m/s]	24
Foundation footprint [m]	dia. 1.8 or dia. 3.6
Weight [ton]	35 or 90