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This report is the 4th edition of TNO[1]'s Offshore Wind Access report. The previous edition [1] was published in 2019 (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 contribution to this report (in alphabetical order):

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[1] ECN, or ECN part of TNO, the organisation which published the previous three editions has joined forces to TNO since April of 2018.

Summary

Offshore wind farms worldwide are moving further away from shore in order to capture more favourable wind conditions. However, this creates additional challenges regarding their Operations & Maintenance (O&M). O&M costs contribute significantly (20-30%) to the Levelised Cost of Energy (LCOE) over the lifetime of an offshore wind farm. One of the main reasons is the relatively low accessibility to the wind farm, which increases the potential downtime and therefore lost energy production, especially for far-offshore wind farms. This has driven the research into innovative access systems which promise average annual accessibility of 90%.

In this fourth edition, an updated overview is presented of commercially available and demonstrated access systems for offshore wind farms. Three categories of access system are identified, based on the point of access towards the wind turbine: i) access to the boat landing, ii) access to the platform of the transition piece, and iii) access to the helicopter hoisting platform on top of the nacelle. Besides the conventional method of access to the boat landing through Crew Transfer Vessels (CTVs), motion compensated gangways mounted on the deck of Walk-to-Work (W2W) Vessels or dedicated Service Operation Vessels (SOVs) have entered the market during the last decade, which has moved large parts of the maintenance base offshore. The analysis in this report shows that the growth of this market is in alignment with the needs for safer and more efficient transfer of technicians and cargo towards the wind turbine.

In addition, while the relatively close-to-shore locations of current offshore wind farms has driven the extensive use of CTVs, more SOVs are being deployed as wind farms move further from shore and wind turbines become larger in size, and new designs for motion compensated gangways and cranes (for SOVs) are being introduced. Furthermore, the following trends are discovered:

- The motion compensated gangway for CTVs are still not well adopted by the industry.

- Within the category of CTVs, the market share of SWATH vessels (a type of CTV with improved seakeeping performance) is increasing.
- In addition to the wind farm installation and (short-term) maintenance campaign, a rising number of dedicated SOVs are entering the offshore wind industry for (long-term contract) daily operation and maintenance (O&M).
- New forms of propulsion such as batteries, hydrogen and hybrids are prototyped to reduce emissions, especially for CTVs.

It is important to model offshore wind farm Installation / O&M activities to fully assess the impacts of a particular access solution. By doing so, design drivers can be identified, business cases of new systems can be established and optimal decisions can be made both for defining the Installation / O&M strategy and choosing between different access solutions. Wind Group of TNO has been constantly developing software tools (e.g. TNO Install, TNO O&M Planner and TNO Despatch) to make such analyses, and will constantly upgrade these tools to improve the fidelity and user-friendliness.

As of 1 January 2020, the formerly ECN part of TNO has been continuing as TNO unit - Energy Transition.

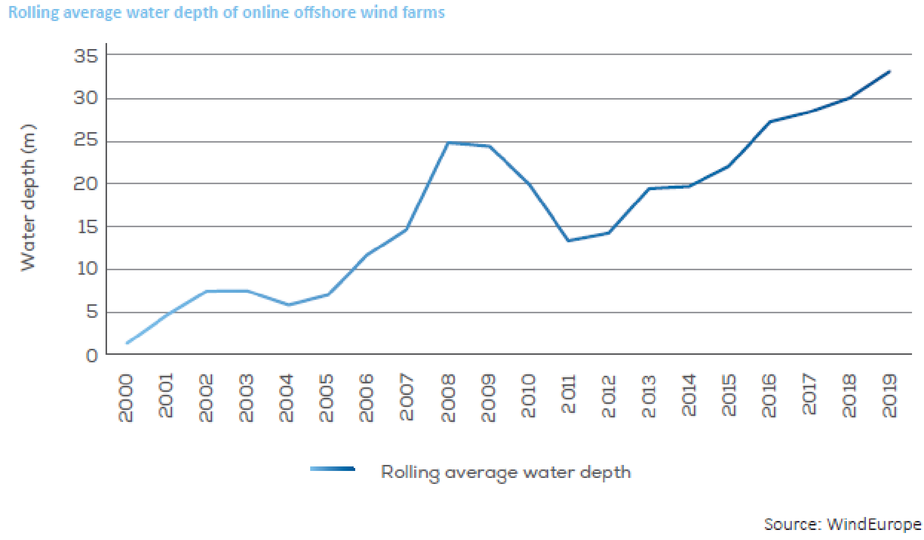
Contents

1 Introduction

Chapter 1 pinpoints the importance of offshore wind access, explains the motivation behind this work and provides the structure of this report.

1.1 Offshore wind O&M background

Offshore wind energy has grown rapidly over the past decade and it is constantly moving further offshore into deeper waters. For European offshore wind farms. Figure 1 presents the increasing trend of the moving averages (of three years) of water depth and distance to shore, while most wind farms are still bottom-fixed. [2]



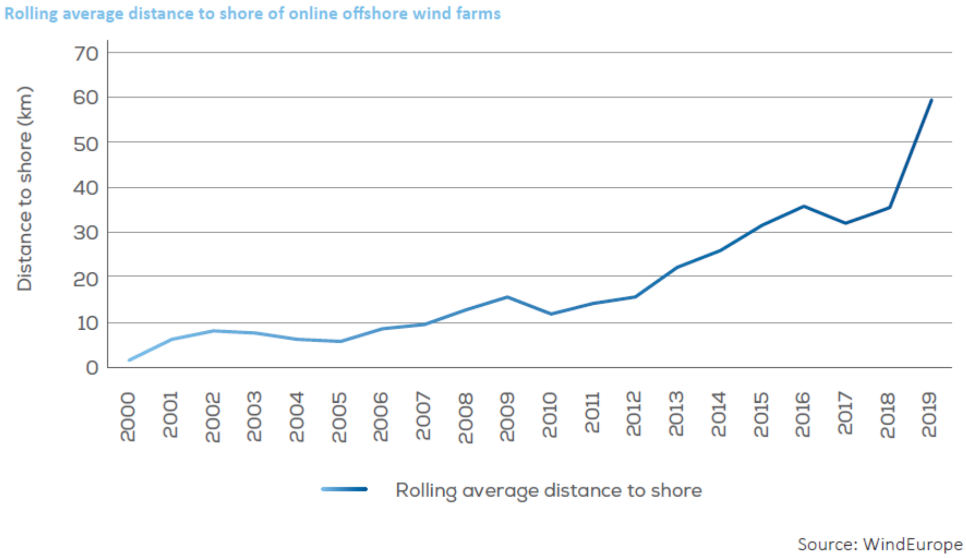


Figure 1 (Above) Rolling average water depth and (below) rolling average distance to shore. [2].

Despite the favourable wind conditions, increasing distance from port leads to higher O&M costs. In an attempt to reduce these costs, new strategies for logistics are being developed using offshore-based accommodations and innovative access gangways.

The distance to port has a large influence on the most suitable strategy, as can be seen in Figure 2. For near-shore wind farms, work-boats (medium sized CTVs, especially catamarans) are most commonly used for daily transit from the port base. The further offshore the wind farm is, the more the travelling time increases, which can significantly reduce the working time available on a turbine. Besides, 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 work-boats are used to transfer technicians. Far-offshore wind farms therefore 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 too short a 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.

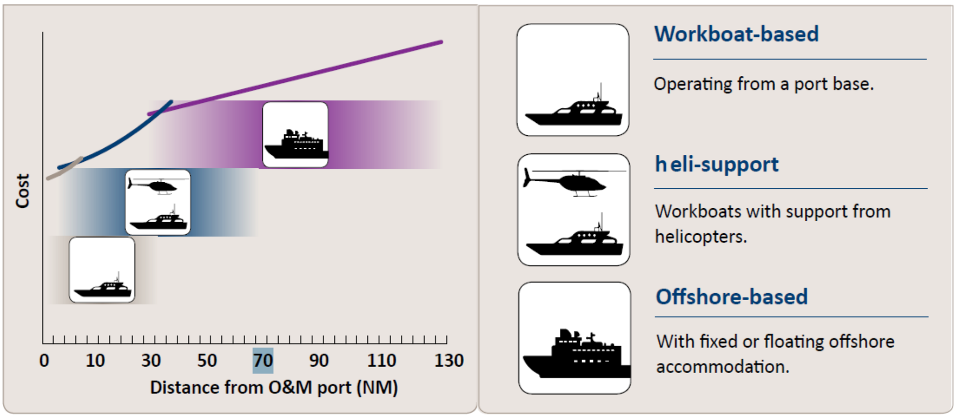


Figure 2 O&M logistics strategy as function of distance from port [3].

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 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 for the economic viability of a project and the source of high uncertainties.

Results of studies [4] reveal that accessibility of at least 80% of the time is necessary to achieve wind farm availability of over 90%. It should be noted that the calculations regarding the accessibility for ship-based access are based on the maximum allowable wave conditions during personnel transfer. Wave conditions are generally described by three parameters: the significant wave height (H_S), the mean zero-crossing wave period (T_Z), and the wave direction. However, limiting wave states have traditionally been described only with significant wave height. For a given access method, this practically means that accessibility can be approximated by the probability of wave height occurrence less than the related limiting significant wave height. Figure 3 shows the result of ECN research: the Cumulative Distribution Function (CDF) of the average annual accessibility to a location close to North Sea oil platform K13, 100km from the Dutch coast, depending on the limiting significant wave height.

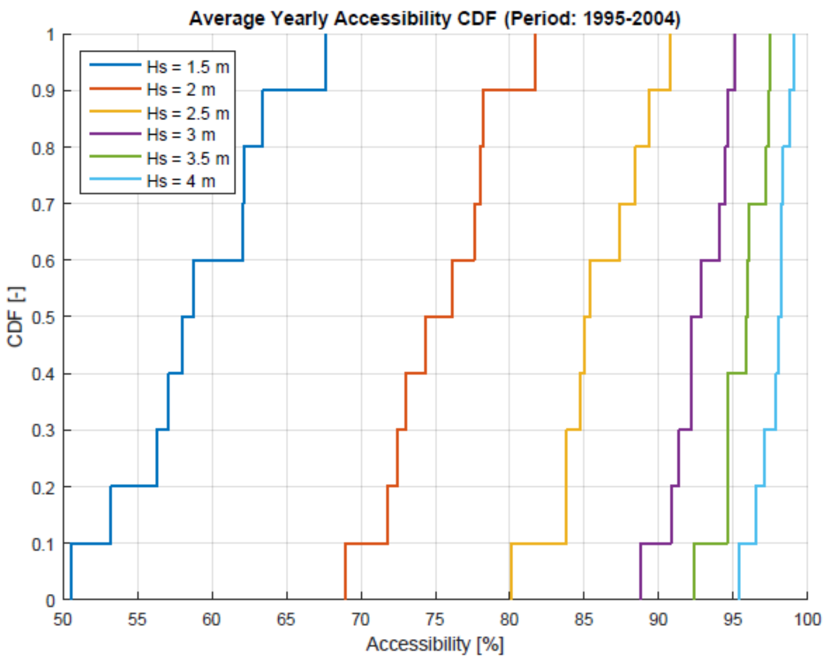


Figure 3 Average yearly accessibility CDF for various max. allowable wave heights (H_S) for the period from 1995 to 2004 at K13 location.

As an example, looking at the (red) 2m Hs line which would be relevant for an access system with that limiting wave height, 50% of years (0.5 on the vertical axis) allow access 75% of the time. According to Figure 3, for an access system operating up to sea states of $H_S = 1.5$m, the expected average annual accessibility ranges from 51% to 68%. Increasing the limit sea state to 2.0 m increases the annual accessibility by 20% whereas a more advanced access system (max $H_S = 2.5$m) would increase accessibility from 75% to 80% annually.

Besides average annual accessibility, the monthly accessibility is also of importance since it indicates the seasonal effect. Figure 4 presents the result of ECN research: the monthly accessibility for a different North Sea location as an average (median) scenario, through the choice of the year 1999.

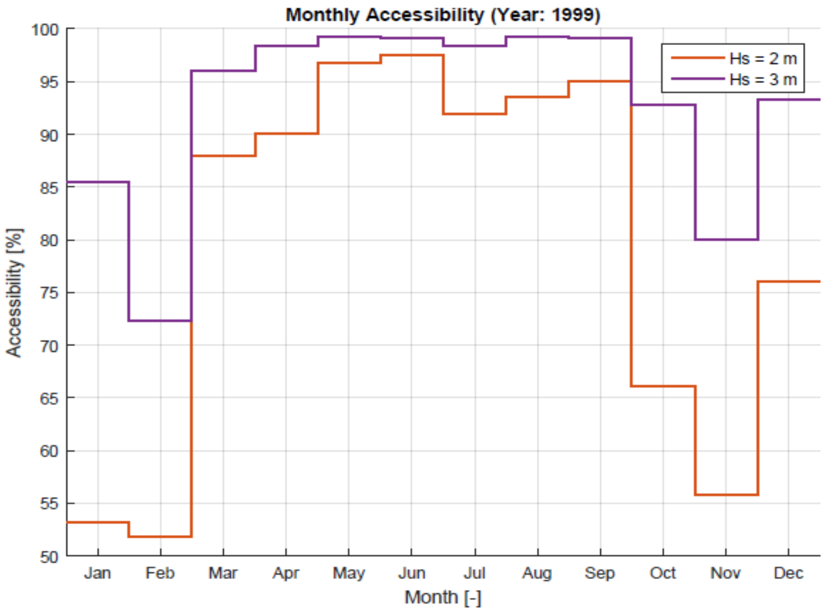


Figure 4 Monthly accessibility for max. allowable H_S of 2.0m and 3.0m for a single year at the North Sea.

In this case, two maximum allowable significant wave heights were used (H_S of 2.0 and 3.0m) in order to make a clear distinction. As expected, the major difference between the two significant wave height limits is during the winter months, where the accessibility drops by 20-30 percentage points for an access system operating up to 2.0m H_S. This leads to an overall annual accessibility of 74% and 92% for H_S of 2.0 and 3.0m respectively.

1.2 Access systems overview

There are essentially three ways to access an offshore wind turbine:
1) at the boat landing at sea level, from where technicians climb the ladder(s) to reach the platform;
2) at the platform, located on top of the Transition Piece (TP) where technicians can enter directly into the turbine tower; and
3) at the helicopter hoisting platform, which provides direct technician access to the nacelle.

Figure 5 shows one example for each access method. In the following sections, the access systems presented are categorized based on their landing/access point.

Figure 5 Access to the boat landing [5], TP platform [6] and helideck/hoisting platform [7] (from left to right).

While presenting this report, it should be noted that the most important characteristic of an access system is the safety/accessibility it can provide.
This is usually defined by the significant wave height (H_S) which is the dominant statistical measure commonly used in the industry. However, the accessibility that an access system can provide in reality is dependent on a combination of factors: not only the motion compensating capabilities of the access system, but also the size and hull design of the vessel on which it is mounted, the location of the access system on the vessel, the manoeuvring capacity of the vessel Dynamic Positioning system, the vessel's power-management system and the sailors manoeuvring the vessel. Therefore, the accessibility provided by an access system cannot be accurately captured by just one environmental parameter. Besides all relevant environmental conditions (wind speed and direction; wave height, direction and period both for swell and wind-waves; current speed and direction), other aspects such as the vessel characteristics should also be taken into account when defining the accessibility such a system could deliver. There is not yet a standard method to define the accessibility that allows one to compare access systems between each other, therefore the accessibility figures mentioned in this report are based on data provided by the manufacturers or designers. Projects are foreseen (a.o. launched with MARIN) to come to more objective and broader capturing of the phrase "workability" or "accessibility".

1.3 Objective and report outline

As already 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 ever larger wind turbines have big impact on the business case of the wind farm. Hence, the market for access systems has evolved rapidly and every year new systems are being introduced. This work intends to present the existing and near 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. To make the distinction between the different systems, the technology readiness level (TRL 1-9) is used, with definitions from EU Horizon 2020 [8]. Relevant here are TRL 7 till 9:

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.

The report is organized as follows: Chapter 1 introduces the background of this report and gives an overview of offshore wind access systems. Chapter 2 and Chapter 3 present the vessels and equipment that provide access to the wind turbine boat landing and wind turbine TP platform, respectively. Chapter 4 describes the method to access the wind turbine from the hoisting platform on the nacelle, which is at this moment by helicopters. Finally, Chapter 5 provides the conclusions and future work.

1.4 Changes with respect to the 2019 Offshore Wind Access Report

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

- The information, values and statistics in the previous edition have been updated based on the latest knowledge and updates from the access systems market.

- The dedicated section about Walk-to-Work vessels and SOVs is updated, including a table showing all the wind farms world-wide which are / will be serviced by SOVs for the daily O&M (data available November 2020).

2 Access to the boat landing

The most commonly used way of accessing offshore wind turbines is through the boat landing, which is mounted in the splash zone of the wind turbine foundation. The reason for its popularity is that it is the most cost-effective and it is a fast solution, especially for near-shore wind farms. Originally, small boats were used by the industry. The increasing volume of the offshore wind industry alongside with the increased knowledge have brought an evolution in CTVs and access support systems on these CTVs: higher safety standards especially during the actual transfers, faster transit to and from the port, enhanced comfort, , better trained crews, larger deck space on the front deck for cargo and last but not least: improved accessibility in bad weather conditions.

2.1 Crew Transfer Vessels (CTVs)

There is a wide range of specialized CTVs that provide fast access to offshore wind farms, located usually in close proximity to a port base. Personnel transfer is accomplished by creating frictional contact between the vessel's specially shaped bow with fender and the wind turbine boat landing to eliminate vessel's translations, commonly known as the “bump and jump" method. CTVs typically carry 12 technicians and cargo such as small spare parts and equipment. Deck cargo is generally lifted from the deck to the platform of the Transition Piece by using the platform davit crane or built-in nacelle crane. Currently, more than 400 CTVs transfer technicians to offshore wind farms. The types of CTVs according to their hull shape include:

1. **Mono-hull**
   The first CTVs that were used in offshore wind farms were mono-hull vessels modified from an existing pool of multi-purpose vessels, which were in use as pilot and merchant marine supportive crew tender boats. Their main advantages are their low cost and scalability. On the other hand, mono-hull CTVs can only operate safely[2] up to sea states of significant wave height of 1-1.2 m due to their low stability while transferring offshore technicians onto the monopile.

2. **Catamaran**
   The majority of CTVs nowadays are aluminium catamarans. The main reasons for their extensive usage are the high speeds that they can achieve during transits and the good seakeeping behaviour in medium sea conditions as well as their improved stability when pushing against the boat landing of a wind turbine for offshore technician transfer. Their disadvantage, compared to mono-hull vessels is their relative higher cost. Catamaran CTVs can typically operate satisfactorily at significant wave heights up to 1.2-1.5 m.

[2] This limit is set by the operational phase when the vessel is actually transferring technicians to/from the wind turbine boat landing. During transit (travelling) phase, the vessel can generally travel at higher significant wave height. The same implication applies to all types of vessel in this report.

3 Trimaran

In an effort to improve seakeeping behaviour of catamarans, trimaran CTVs entered the market. Transfer of technicians is possible up to sea states of typically 1.5-1.7 m H_S.

Figure 6 Monohull [9], Catamaran [10] and Trimaran [11] CTVs (from left to right).

4 Small Waterplane Area Twin Hull (SWATH)

The market share of SWATH CTVs is constantly increasing, especially in the field of wind farm installation and commissioning when a large number of technicians has to be transferred to the wind turbines in a short period of time. SWATHs are catamaran-like vessels, which achieve greater stability by minimizing the hull cross section area at the sea's surface. Their disadvantage is higher cost and lower speed compared to catamarans. Their design allows comfort during transit and safe access at significant wave heights of typically 1.7-2.0 m.

5 Surface Effect Ship (SES)

The technology of SES has also been adopted for CTVs. The hull shape of SES CTVs is similar to catamarans but most of the vessel's weight is lifted by an air cushion, which provides high stability/comfort allowing high vessel transit speeds, less fuel consumption and good seakeeping behaviour. This however comes with the disadvantage of design complexity and higher construction costs. Overall, SES can operate at maximum sea states of typically 2.0 m H_S during transfer phase. Note that only a very limited number of these types of vessels have been built.

Figure 7 SWATH [12], SES [13] and TRI SWATH [14] CTVs (from left to right).

Table 1 shows an overview of typical values of the characteristics of the aforementioned CTV types. It should be noted that the values do not exactly represent the CTVs displayed in Figures 6 and 8.

Table 1 Typical characteristics of CTV types

	Mono- hull	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
Passengers [-]	12	12	12	12/24	12/24
Cargo [tons]	5 - 10	10 – 15	1 - 5	2 - 10	3 - 5
Hs (limit) [m]	1 - 1.2	1.2 - 1.5	1.5 – 1.7	1.7 - 2	1.8 – 2.2

Traditionally CTVs are diesel-driven and the design has been mainly focused on achieving higher speed and lower fuel consumption during the transit and optimising seakeeping features. Less focus has been given to optimising the performance (e.g. fuel consumption) during idling and transiting at low speed. As the regulations for greenhouse gases emission are getting stringent, the past years have been witnessing a trend towards electrical, hydrogen, hybrid propulsion systems and new hull (shape) designs of CTV are being researched, designed and prototyped, aiming to reduce emissions and fuel consumption when the CTVs are at low speed.

2.2 Service Accommodation Transfer Vessels (SATVs)

As the turbines are located further offshore, in order to reduce the levelised cost of energy, SATVs are designed to stay offshore longer, making one transit to and from the wind farm once per week, rather than daily transits. SATVs allow more technicians to stay on board and stay overnight, hence SATVs are larger and have higher seakeeping performance compared to CTVs. However, SATVs still function as CTVs, pushing against the boat landing to transfer technicians. Compared to service operation vessels (SOVs, see Chapter 3.1), SATVs are easier to manoeuvre between turbines. In short, SATVs are seen to fill the gap between CTVs and SOVs, in terms of operational versatility, design complexity and costs.

Currently several SATV designs are under development [15], and only one has been built, which is Ventus Formosa, designed by BMT in the UK and owned by Ventus Marine. The 36.3m vessel can cruise at 16 knots, transit at a sprint speed of 19 knots, and allow 10 personnel to stay onboard for 12 days offshore. It is currently serving O&M support for Taiwan's Formosa 1 wind farm. [16]

Figure 8 BMT-designed Service Accommodation Transfer Vessel [16].

2.3 Systems that enhance access to the boat landing

The demand for high availability of the wind farm has pushed the development of systems that can be fitted to enhance accessibility and overall safety. These systems can either be mounted on the vessel foredeck to compensate motions, or on the wind turbine foundation structure. Both methods improve access to the boat landing ladder. The requirements for the vessel characteristics (e.g. length) and the boat landing vary for each system as well as the compensation method (active or passive).

In this section only two commercially available systems have been identified. There are several additional systems existing on the market, which have been excluded in this version of report (e.g. Houlder's TAS; MOBIMAR Gripper, Osbit MaXccess T-Series) because they are currently not actively deployed.

An overview of commercially available systems that enhance the performance of CTVs is presented in Table 2, stating their relevant technical parameters.

Table 2: Main data of commercially available systems that enhance the access to the boat landing

	Ampelmann L-Type	Uptime
		15 m
Minimum length gangway [m]	8	7
Maximum length gangway [m]	13	15
Maximum working angle +/- [deg.]	±17 (range of 6.8m)	±30
Height from deck [m]	-	Custom
Vertical reach [m]	±3.4m (range of 6.8m)	4m
Gangway width [m]	0.6	0.8
System weight [ton]	8	3.5
Footprint on vessel [m^2]	2.2 m x 6.6 m	5 m^2
Limiting wave condition Hs [m]	2	2
Vessel length [m]	>30	>25
Mobilization time [hr]	8	12
Deployment time [s]	60	24
Maximum connection time [hr]	-	No limit
Power consumption [kW]	22	25
Maximum load [kg]	150	500
Number of systems built [-]	8	10
Number of transfers [-]	> 200,000	>120,000

Notes:

1. Systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data were not made available.
2. The table provides an overview of commercially available and demonstrated systems that enhance the access to the boat landing, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

2.3.1 *Commercially available access systems to the boat landing*

Ampelmann L-Type

Ampelmann 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.

Figure 9 Ampelmann L-Type [17].

Uptime Gangway 15m for boat landing

Uptime's small gangways are telescopic motion compensated gangways, suitable for a variety of vessels, with or without DP. This gangway can be connected to a gripper that holds the gangway in position with the boat landing, or by rollers that can be landed on any flat surface. In the latter case the gangway is actively motion compensated. The ten systems together have provided more than 120,000 transfers at sea.

Figure 10 Uptime Gangway 15 m (courtesy of Uptime International).

3 Access to the Transition Piece (TP) platform

The restricted accessibility that CTVs can provide, the impact of safety-related risks and the effect on humans due to motion-induced fatigue are causing new solutions to be considered, which provide safer and more comfortable access directly to the TP platform at elevation from the sea level of approximately 15m - 20m. As wind farms move further offshore, accommodation near the offshore wind farm becomes more cost-efficient. For this reason, Walk-to-Work (W2W) solutions have been developed, which refer to a Dynamic Position vessel (mostly called support vessel or accommodation vessel), usually longer than 60m, with a motion compensated gangway to eliminate relative motions between vessel and wind turbine.

Figure 11 Walk-to-Work vessels Vroon VOS Start [18] and Bibby Wavemaster [19].

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

At the moment, the majority of the Walk-to-Work (W2W) vessels used in the offshore wind sector are retro-fitted vessels from the oil & gas industry, with permanently or temporarily-installed motion compensated gangways. W2W vessels are mostly employed in the installation phase of offshore wind farms, especially during infield cable installation and wind turbine commissioning. W2W vessels are now also increasingly used for the scheduled maintenance campaigns of wind farms and substations. Since 2015, Service Operation Vessels (SOVs), which are purposely built W2W vessels dedicated to servicing the installation and daily O&M of offshore wind farms have come to the market. Compared to the retro-fitted W2W vessels, these purpose-designed SOVs generally have better performance in terms of transferring technicians and cargo, because those vessels are designed in an integral manner with the motion compensated gangways onboard (and cranes, if any), hence the parameters such as the location of the gangway/crane, the layout of the deck and technician/cargo logistics can be optimised during the design.

There are several advantages of using SOVs for the installation and O&M of offshore wind farms:

- SOVs are offshore-based near the wind farm, which saves time bringing technicians to the wind farm and thus increases their effective working time on turbines. According to the working regulations in Europe, offshore-based technicians normally work on a rotation of two weeks. Therefore, the SOVs used for the wind farm daily operation follow the same working pattern. Every two weeks the SOV travels back to port for crew change, reloading cargo storage and bunkering, which generally takes a day. During this change of shift, the trips between the wind farm and port are normally made in the night, hence the working time of technicians is not reduced when they work daytime only.

- Since the technicians on SOVs are offshore-based, they can have a staggered working pattern, meaning that the working shift of technicians can start only when they are being transferred to the wind turbine. In general, the SOVs employed for wind farm O&M need to transfer multiple teams of technicians to different turbines in one day. Due to the staggered working pattern, the working time of technicians to be transferred later in a day is not reduced while the vessel is travelling or transferring earlier teams. This also increases the effective working time of technicians compared to the shore-based access strategy, where the working shift of all the technicians start at the same time when they are going to the wind farm from the port.

- The enhanced accessibility of SOVs results in longer weather windows for installation, commissioning or maintenance activities. This is the main reason why SOVs are widely used during installation (commissioning phase) of the wind farm, even when the wind farms are close to shore. The motion compensated gangway on SOVs can provide much easier and safer transfer of technicians and cargo to the wind turbine, compared to the access by boat landing. In order to further improve the efficiency and safety during transfer, many new SOVs are adopting a “step-less” approach, which means that technicians do not need to step up (or down) during the entire transfer process from the cargo deck / accommodation to the wind turbine TP platform. The step-less approach also allows for transfer of small size cargo (<200 kg) with trolleys/pallets, instead of being carried by technicians. In general, the step-less approach is achieved with the help of the integrated lift in the SOV and the motion compensated gangway.

- The better seakeeping behaviour of SOVs compared to CTVs causes less motion-induced fatigue to technicians, which has a positive effect on the performance of technicians.

On the other hand, SOVs also have some disadvantages:

- SOVs are much more expensive than CTVs. The day rate of an SOV is approximately 8 – 10 times that of a CTV. This is the main reason why most of the near-shore wind farms are still operated with CTVs. During the installation phase of wind farm, technicians can work on two shifts (day shift and night shift), hence the high costs of SOV can be “halved” by using it twice as efficiently. However, this is not the case for the O&M phase, during which technicians normally work only during the day shift.

- The transit speed of SOV in the wind farm is very slow (10 – 12 knots), especially when sailing on Dynamic Positioning mode. In a large wind farm, an SOV may take a very long time travelling between turbines that are far away from each other. To solve this problem, and meet safety requirements for emergency evacuations, some of the SOVs are equipped with daughter craft (usually fast cruising boats of 7-15 m) which can be launched by the davit crane on the vessel.

However, the daughter craft can only operate in very good weather, preferably when the significant wave height is under 1.2 m.

As more and more offshore wind farms are located further offshore and having larger capacity, the rise of SOVs for daily O&M has been noted as a trend. Up until the end of 2020, it is known that the offshore wind farms summarised in Table 3 are / will be serviced by SOV for the (long term) O&M phase.

Table 3 The offshore wind farms which are / to be serviced by SOV for long term O&M (knowledge by the end of 2020)

Wind Farm	Country	Distance to Port	No. of Turbines	Year (to be) Commissioned	SOV for O&M	Motion compensated gangway on SOV
BARD Offshore 1	DE	110 km	80	2013	Acta Auriga	SMST TAB-L
EnBW Baltic 2	DE	60 km	80	2015	Esvagt Froude[3]	Ampelmann A-type
Butendiek	DE	40 km	80	2015	Esvagt Faraday	Ampelmann A-type
Gemini	NL	75 km	150	2016	Windea La Cour	Uptime 23.4m
Belwind 1 Nobelwind	BE BE	45 km 45 km	55 50	2010 2017	Esvagt Mercator	None[4]
DanTysk Sandbank	DE DE	75 km 100 km	80 72	2015 2017	Windea Leibniz	Uptime 23.4m
Veja Mate	DE	110 km	67	2017	Acergy Viking[5]	Uptime 23.4m
Dudgeon	UK	45 km	67	2017	Esvagt Njord	Uptime 23.4m
Race Bank	UK	40 km	91	2018	Edda Passat	Uptime 23.4m
Borkum Riffgrund 1 Gode Wind 1 & 2 Borkum Riffgrund 2	DE DE DE	60 km 55 km 60 km	78 97 56	2015 2017 2019	Wind of Change	Uptime 23.4m
Merkur	DE	60 km	66	2019	Wind Jules Verne	Uptime 30m
Hohe See and Albatros	DE	110 km	87	2019	Bibby WaveMaster Horizon	SMST TAB-L
DeBu (Deutsche Bucht)	DE	110 km	33	2019	Esvagt Albert Betz	SMST TAB-L
Hornsea 1	UK	120 km	174	2020	Edda Mistral	Uptime 23.4m
Rentel Seamade (Mermaid + Seastar)	BE BE	40 km 50 km	42 58	2018 2019/2020	Groene Wind	SMST TAB-L
Borssele 3 & 4	NL	50 km	77	2021	A new SOV of Esvagt (to be named)	SMST TAB-L
Triton Knoll	UK	50 km	90	2021	A new SOV of Esvagt (to be named)	SMST TAB-L
Moray East	UK	70 km	100	2021	A new SOV of Esvagt (to be named)	SMST TAB-L
Hornsea 2	UK	89 km	165	2022	Wind of Hope	Horizon V5
Greater Changhua	TW	35-60 km	111	2022	A new SOV of Ta San Shang Marin Co. Ltd.	SMST TAB-L
Revolution Wind South Fork Wind Sunrise Wind	US US US	40 km 45 km 48 km	88 15 110	2023 2023 2024	A new SOV of Edison Chouest Offshore (to be named)	Not known yet

[3] The service contract (2005 to 2020) is finished this year.
[4] Esvagt Mercator is not equipped with motion compensated gangway. Instead, it uses daughter craft onboard to transfer technicians.
[5] Will be replaced by a new SOV.

It should be noted that Table 3 does not cover all the existing and to-be-built SOVs in the offshore wind sector, as some SOVs (e.g. Bibby WaveMaster 1, VOS Start) are currently on other duties than servicing the O&M of offshore wind farms.

3.2 Motion compensated systems for transfer of personnel

There are two modes of motion compensation: active and passive. Active motion compensation uses sensors and control systems to eliminate relative motions. Passive compensation is achieved by a mechanical connection which adjusts itself passively. Offshore wind access through motion compensated gangways is a relatively new market and new systems are constantly being developed. Effort has been made to include most of them in this publication. Besides motion compensated gangways, there are also other systems that can be installed on vessels and transfer technicians to the TP platform.

The majority of the systems providing direct access to the TP's work platform for personnel are active motion compensated gangways. Increasing numbers of them also provide lifting capacity for larger cargo, in most cases up to 1000 kg.
There are also some motion compensated cranes that are additionally capable to transfer personnel through some sort of basket. In this section, an overview of commercially available and prototyped motion compensated systems that transfer personnel to TP's work platforms is presented. The relevant technical characteristics are summarised in section 3.2.1, after which these systems are categorised and presented respectively in section 3.2.2 (for commercially available systems) and section 3.2.3 (for demonstrated systems which are not yet deployed).

3.2.1 Overview of characteristics

An overview of the relevant technical characteristics is given in the tables below.

Table 4-1: Main data of commercially available and demonstrated motion compensated access systems that provide access directly to the TP platform.

	Ampelmann							Barge Master		
	A-Type		E-Type		SOV-type		N-Type	Basic	Height Adjustable with elevator	Height adjustable with elevator XL
	Hydraulic	Electric	E1000	E5000	28m	32m				
Min. length gangway [m]	16	16	21	22	17	21	23	14.9	14.9	19.9
Max. length gangway [m]	25	25	30	31	28	32	32	25.1	25.1	30.1
Max. work. angle +/- [deg.]	±17	±17	-17/+65	-17/+65	±17	±17	±15	23	23	23
Height from deck [m]	5.4	6	9.5	10.5	20 - 25	20 - 25	12	Any required	Any required	Any required
Vertical reach [m]	12	12	14.9	35	6.3 – 22.9	6.3 – 22.9	15	14.5	24.4	12 – 29.5 m
Gangway width [m]	0.55/1.2	0.55	0.55	0.65	1.2	1.2	0.8	0.9	0.9	1.2
System weight [ton]	39	35	105	152	85	90	225	28	28 for gangway, 54 for elevator with pedestal	35 for gangway, 54 for elevator with pedestal
Footprint on vessel [m²]	41.8	36	95	95	16	16	11 m x 11 m	Ø 1.9 m	3.3 m x 3.3 m	3.3 m x 3.3 m
Limiting wave condition Hs [m]	3 (3.5 for A^{EP})	3	4.5	4.5	3.5	3.5	3.5	>3.5	>3.5	>3.5
Vessel length [m]	>55	>55	>70	>70	>70	>70	>70	-	-	-
Mobilization time [hr]	12	12	48	48	Integrated	Integrated	60	24	168	168
Deployment time [s]	60	60	60	60	45	45	120	32	60	60
Max. connection time [hr]	-	-	-	-	-	-	-	No limit	No limit	No limit
Power consumption [kW]	2 x 200	50	2 x 400	2 x 400	172	172	2 x 450	2 x 200	2 x 200	2 x 300
Max. load [kg]	300 for gangway, 600 for lifting	200	1000	5000	1000/2000	1000/2000	450	1000	1000	2000
Number of systems built [-]	40	2	>15	1	-	-	1	3 built, 2 under construction	1 built, 2 under construction	0
Number of transfers [-]	>3,000,000		>1,500,000	-	-	-	>20,000	>35,000	>40,000	N/A

Notes:
1. Systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated access systems, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

Table 4-2: Main data of commercially available and demonstrated motion compensated access systems that provide access directly to the TP platform.

	EAGLE-ACCESS*	KENZ		Lift2Work OPTS 24/400	MacGregor			Royal IHC	
		EH 15-25/1800	EH 16-26/1800		Horizon V4	Horizon V5 26m	Horizon V5 30m	AMC-38	Sea-Link©*
Min. length gangway [m]	N/A	14.6	17.1	12	20	17	20	26	20
Max. length gangway [m]	27	24.6	27.1	24	30	26	30	38	30
Max. work. angle +/- [deg.]	N/A	±15	±18	+65	15	15	15	+25/-20	±25
Height from deck [m]	23	custom	custom	20	12-30	15-25	15-25	Custom	Custom & variable
Vertical reach [m]	0/+25	13	19	24				-	-
Gangway width [m]	N/A	0.8	1.2	2.4	1.5	1,5	1,5	1.2	0.9 - 1.2
System weight [ton]	27	32.1	49.3	15 –20	60-90	60-75	60-75	-	-
Footprint on vessel [m^2]	4	40	12	8.8 m^2 (40'')	12.8	5,4	5,4	3 m x 3 m	3 m x 3 m
Limiting wave condition Hs [m]	4.5	1.5	>3	2.5 – 4	4	4	4	4	> 4
Vessel length [m]	>60	88	83.7	>40	>65	>65	>65	>80	Any required
Mobilization time [h]	8	48	48	8/ one day	48	48	48	-	-
Deployment time [s]	60	120	120	60	<30	<30	<30	60	60
Max. connection time	N/A	No limit	No limit	-	4	4	4	No limit	No limit
Power consumption [kW]	75	200	260	2 x 75	400	300	300	2x140	Up to 2x225 or less
Max. load [kg]	1000	300	500/1000	500/2000	750 / 1500	750 / 1500	750 / 1500	1000	1000
Number of systems built [-]	1 built	2	1	1 built, 2 under construction	2 under construction	2 under construction	2 under construction	1	0
Number of transfers [-]	0	>20,000	>10,000	<100	0	0	0	>1,000	0

Notes:
* Systems with star-sign means it is currently in the phase of demonstration.
1. Systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated access systems, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

Table 4-3: Main data of commercially available and demonstrated motion compensated access systems that provide access directly to the TP platform.

	Safeway			SMST		
	Seagull	Gannet	Osprey	TAB M	TAB L	TAB XL
Min. length gangway [m]	18	18	22	13	15/19	28 – 38
Max. length gangway [m]	28-30	30-32	32	21	25/31	43 – 58
Max. work. angle +/- [deg.]	±15	±15	±15	+25/-20	+25/-20	+27/-23
Height from deck [m]	6-16			Up to 30	Up to 30	Variable
Vertical reach [m]	17	custom	custom	16	19	46
Gangway width [m]	1	1.2	1.2	0.6	0.9 – 1.2	1.5
System weight [ton]	90	75	80	-	-	-
Footprint on vessel [m^2]	30	30	33	20 ft container	various	Ø 3.2 m
Limiting wave condition Hs [m]	3.5	3.5	3.5	2.5 – 3.5	3 – 4	>4
Vessel length [m]	>60	>60	>60	SOV, FCS, various	SOV, CSV, various	SOV, CSV, various
Mobilization time [h]	24			24	-	-
Deployment time [s]	60	60	60	150	150	-
Max. connection time	No limit	No limit	No limit	-	-	-
Power consumption [kW]	75-85	75-85	30-100	55	100	86
Max. load [kg]	1000 for lifting	2000 for lifting	1000 for lifting	300	1000/6000	10000
Number of systems built [-]	6 built, 3 under construction		2 under construction	9 built, 3 under construction	7 built, 5 under construction	5
Number of transfers [-]	-	-	-	-	-	-

Notes:
1. Only systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated access systems, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

Table 4-4: Main data of commercially available and demonstrated motion compensated access systems that provide access directly to the TP platform.

	Uptime						Z-bridge	
	23.4 m	30 m	40 m	42.5 m	46.5 m	57 m	W2W	B2W*
Min. length gangway [m]	15.4	20	25	30.5	30.5	37	15	18
Max. length gangway [m]	23.4	30	40	42.5	46.5	57	24	27
Max. work. angle +/- [deg.]	+15/-10	±20	±20	+24/ -16	+24/ -16	+24/ -16	±15	15 - 55 deg
Height from deck [m]	Custom	Custom	Custom	Custom	Custom	Custom	13	7-21 m
Vertical reach [m]	7.1	19	20	20	22	26	12.5	
Gangway width [m]	1.2	1.2	0,9	1.2	1.2	1.5	1.2	1.2
System weight [ton]	28	36	50	78	40	140	50	23
Footprint on vessel [m^2]	10	10	15	20	20	30	15	5
Limiting wave condition Hs [m]	3.5	4.5	4.5	6.0	6.0	6.0	4	3
Vessel length [m]	>60	>60	>60	>80	>80	>80	>50	CTV/Mini SOV/ Large SOV
Mobilization time [h]	30	30	50	50	50	60	36	12
Deployment time [s]	60	60	90	180	180	180	60	60
Max. connection time	No limit	No limit	No limit	No limit	No limit	No limit	No limit	No limit
Power consumption [kW]	320	550	300	210	230	500	50	50
Max. load [kg]	700	3,000	1,000	3,600	3,600		1,000	1000
Number of systems built [-]	26	2		30	24	1	1	1
Number of transfers [-]	~1,000,000	500		~10,000,000	~1,000,000		>1200	Start ops. Q4 2020

Notes:
* System with star-sign means it is currently in the phase of demonstration.
1. Only systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated access systems, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for limiting wave conditions (significant wave height, or Hs) are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, manoeuvring capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

3.2.2 Commercially available motion compensated systems for transfer of personnel

This section lists the systems that are currently available on the market (TRL 9). There are several additional systems existing on the market, which have been excluded in this version of report (e.g. Osbit MaXccess AM- and P-Series) because they are currently not actively deployed. MacGregor Horizon V4, V5 systems are not elaborated on due to currently limited information.

Ampelmann A-Type

Inspired by the Stewart platform, the Ampelmann system eliminates any relative motion by taking real time measurements of the ship's motions and then actively compensates the motions by using six hydraulic cylinders, known as the hexapod. The first concept was A-Type. Ampelmann A-Type series currently has four models: A, A^{EP}, A100 and A400, which vary in size, maximum operational sea states and capability of cargo transfer.

Figure 12 Ampelmann A-Type (courtesy of Ampelmann)

With additional motion compensation at the base of the gangway which works jointly with the hexapod, A^{EP} provides an enhanced performance with a higher maximum operational sea state compared to other A-type models (see Table 4). Size-wise, A400 has a wider gangway of 1.2m, compared to the other A-type models with 0.55m gangway width. In terms of cargo transfer capability, Ampelmann A and A^{EP} can only transfer personnel, while A100 and A400 are also suitable for transferring small-sized cargo. A100 has a basket at the tip of the gangway which can take loads up to 100 kg and A400 allows to use electric trolleys through the elevator and gangway to transfer load up to 400 kg in a stepless approach. All critical components are installed redundantly to ensure constant and safe operation. The A-type has been in production since 2008 and it is the most commonly used Ampelmann type in the offshore wind sector, especially A model and A^{EP}.

In addition to the existing models which are hydraulically driven, an electric model A-type will soon be available. The electric model uses electric cylinders instead of hydraulic cylinders, and can be directly powered by the electricity supply from the vessel. The switch to electric actuation allows for power regeneration during parts of the compensation cycle. This energy is temporary stored in ultracaps and re-used in actuating the system. The reduced losses in the electric system combined with regeneration, results in a significant reduction of the energy consumption. In addition, the electric model has integrated a balanced heave compensation technology which further reduces the power consumption. Since a separate hydraulic power unit is no longer required, the electric model also saves weight and deck space compared to the hydraulic A-type models.

Ampelmann E-Type

The Ampelmann 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 All the E-type models can transfer technicians in sea states up to 4.5m. The model E1000, E5000, can also transfer cargo in crane configuration, with capacity of 1000kg and 5000kg, respectively. The transformation from the gangway to crane configuration (and vice versa) takes less than one minute.

Figure 13 Ampelmann E-Type (courtesy of Ampelmann)

Ampelmann N-Type

Ampelmann's 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.

Figure 14 Ampelmann N-Type [20]

Ampelmann SOV-Type

Ampelmann's latest development, SOV-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. As for cargo transfer, the gangway supports trolley operation up to 400 kg and has a lifting capacity of 2 ton in crane mode.

Figure 15 Ampelmann SOV-Type (courtesy of Ampelmann)

Barge Master Motion Compensated Gangway

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 last year, several additional features on the Barge Master motion compensated gangway have been developed:

- A tip ladder 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 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 the existing systems.
- The system can run on biodegradable oil.

Figure 16 Left: Barge Master gangway on height adjustable pedestal with elevator [21]; Middle: the tip ladder (courtesy of Barge Master); Right: Barge Master gangway on fixed pedestal (courtesy of Barge Master).

Kenz Cranes EH-15-25/1800

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.

Figure 17 Kenz EH-15-25/1800 gangway (courtesy of Kenz).

Kenz Cranes EH-16-26/1800

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 [22].

Figure 18 Kenz EH-16-26/1800 gangway (courtesy of Kenz).

Lift2Work Offshore Passenger Transfer System (OPTS 24/400)

OPTS 24/400 by Lift2Work is a fully compensated (in 6 degrees of freedom) system that can be mobilised in a large variety of vessels. Designed to be executed as a 40 foot HQ container, the OPTS can be quickly mobilised and demobilised within one day. The OPTS has the ability to move freely 360 degrees with an outreach of 24m. A maximum of 6 persons can be transferred at the same time. Besides transferring personnel, OPTS can also be used as a fully compensated crane with lifting capacity up to 2000 kg on the wire and 500kg in the basket (while the operator is allowed to be in the basket at the same time). Due to its specific design, the system is considered as one of the few tools which can replace the rope access work under the platform, hence it is considered suitable for the decommissioning work in offshore wind farms. The system was built, tested and certified in 2018.

Figure 19 OPTS 24/400 in transportation (courtesy of Lift2Work)

Figure 20 OPTS 24/400 in operation (courtesy of Lift2Work)

Royal IHC AMC-38

Developments within Royal IHC with regards to active motion compensated access systems date back to 2010, and the first system was delivered in 2017. With a length of 38m it 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.

Figure 21 Royal IHC AMC-38 Gangway, courtesy of Royal IHC.

Safeway Seagull

As the first motion compensated gangway system developed by the Van Aalst Group, Safeway Seagull has been operational since 2017. The Safeway Seagull type is developed for retrofitting on existing vessels as a plug-and-play solution for campaigning. It comes with an integrated vertical elevation feature with 10m range, allowing level offshore access at various sites. As a highlight, the system is featured with roll compensation at the base of the mast, and a moving counterweight at the back of the gangway to improve the heave compensation, which is quite rare in the market. 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.

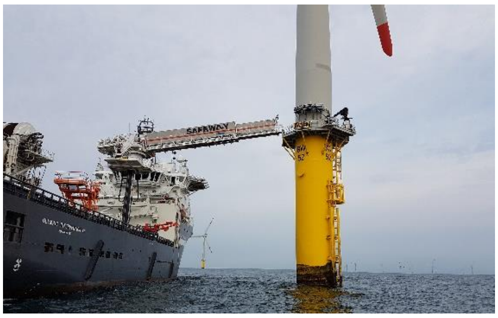


Figure 22 Safeway Seagull gangway [23].

Safeway Gannet

Safeway has recently introduced the hull integrated gangway system *Safeway Gannet* in the market, designed especially for the new-built SOV's. The system incorporates the advantages of the Seagull model (hover mode, roll compensation and counterweight). Furthermore, with 1.2m gangway width, Safeway Gannet offers a stepless transfer with trolley operations from the vessel warehouse to the offshore structure. Safeway Gannet of Van Aalst Group is designed for installation on the new-built SOV's.

Figure 23 CAD-drawing of Safeway Gannet (courtesy of Van Aalst)

Safeway Osprey

Figure 24 CAD-drawing of Safeway Osprey (courtesy of Van Aalst)

Safeway Osprey of Van Aalst Group is designed for wind farm installation vessel. It is a self-sustained system which can be relocated to any location on the deck to meet specific project requirements or deck arrangements. Compared to Safeway Seagull, Safeway Osprey does not have roll compensation. However, it has an extended gangway length (22m – 32m), wider gangway (1.2m) and larger vertical elevation range (12m). Currently two Safeway Osprey systems are being constructed for wind farm installation vessels, One is a hull integrated version for the Alfa Lift 1 and the other is a standalone deck type for the DEME Orion. It should be noted that all the Safeway systems (Seagull, Gannet, Osprey) can allow 3 people walking on the gangway at the same time, thus capable of transferring 200 people in 15 min.

SMST TAB M, L and XL

There are three versions (M, L and XL) of the SMST gangway, Telescopic Access Bridge (TAB), designed for direct access to the platform through large vessels. The TAB-M and TAB-L have a modular setup and can be applied to various landing heights using container frames as stacking modules (as shown in the first picture of Figure 25). 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. The M and L types can offer both active and passive motion compensation, whereas the XL version can only compensate the motion passively when connected with the offshore structure. All gangways can be deployed for cargo handling in hoisting mode (with hook at the tip).

Figure 25 SMST TAB: M series, L series and XL series (courtesy of SMST).

Uptime Gangway

Uptime's large active motion compensated gangways (either 23.4m or 26m) have been on the market since 2012 and they have an extensive track record. The 23.4m version has been produced 26 times and the 26m version 2 times. These units are delivered both with bumper mode and cone type landing, subject to duration and suitability of landing area. The new 30m unit (both Type 1 and 2) is world's first autonomous gangway with artificial intelligence [24], designed with autonomous landing function for increased safety (no operator cabin on the gangway). Furthermore, the 30m version can be equipped with an integrated crane function with lifting capacity up to 6 ton. Currently two 30m gangways have been delivered – a 30m Type 1 for Island Clipper and a 30m Type 2 for Windea Jules Verne.

Besides the active motion compensated gangways, Uptime also delivers larger but passive motion compensated gangways (42.5m / 45.5m / 46.5m) for 24/7 connection (mostly used in the Oil & Gas industry). These large versions have been delivered more than 80 times, according to Uptime's statistics. The one-off active motion compensated 57m version is delivered and installed on the Edda Fortis Accommodation Vessel. Most of the gangways produced by Uptime International are being sold, but the company has also built up a rental pool of assets in the recent years.

Figure 26 Uptime 23.4m (courtesy of Uptime International).

Figure 27 Uptime 45m [25].

Figure 28 Uptime 30m (courtesy of Uptime International)

Zbridge W2W

Operational since 2019, Zbridge W2W by ZTechnologies is a patented motion compensated gangway system that eliminates the rotative (pitch & roll) movement of the mast. The system's elevator currently 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. Due to the height adjustable mechanism the landing height is adjustable from 2.5m up to 23m.

Figure 29 Z-Bridge W2W (courtesy of Z-Bridge)

3.2.3 *Demonstrated motion compensated systems for transfer of personnel*

The previous section listed commercially available systems. This section will show the systems which have been demonstrated at a prototype level (TRL 7-8) but have not been commercially deployed yet.

EAGLE-ACCESS

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 center 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 will be 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 system.

Figure 30 EAGLE-ACCESS (courtesy of EAGLE-ACCESS)

Royal IHC Sea-Link®

Royal IHC has also developed the Sea-Link®, a compact gangway system specifically designed for SOVs. The digital model has been prototyped with simulation, and physical model tests have been performed at MARIN. Besides, some parts of the system have been implemented already in the operational gangway AMC-38. One of the major features of this system is the introduction of the patented Inter-mediate Platform on the gangway which can significantly reduce the telescoping motion thus improve the safety during technician transfer. Furthermore, *Sea-Link®* is a part of the integrated digital environment being developed by Royal IHC, along with an autonomous SOV, IHC Dynamic Positioning system, Path Planner and a digital twin, to enable autonomous operations (including sailing through the wind farm, approaching the turbine and landing the gangway autonomously) and optimal performance of the entire system.

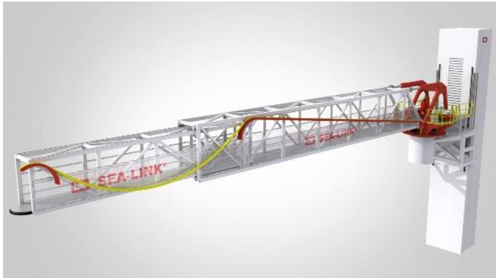


Figure 31 CAD-drawing of Royal IHC Sea-link [26].

Zbridge B2W

Zbridge B2W is a newly built system that is based on the patented motion compensated pedestal of the Z-Bridge W2W system, but 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 crane to hoist up to 3 ton of cargo from the deck to the TP. Weighing only 25 ton, the system allows it to be installed on a CTV, which is able to transfer from vessel deck to the TP while the CTV thrusts against the boat landing area. The system has already been set out for sea trial in November 2020.

Figure 32 Left: Z-Bridge B2W (courtesy of Z-Bridge). Right: Z-Bridge B2W in sea trial [27].

3.3 Motion compensated cranes for components between 1 and 20 metric tons

It is equally important to transfer cargo to the offshore structures as personnel. For maintenance purposes, it is mostly required to have tools and parts transported to the wind turbines and to substations (individually, in crates or in small containers). Depending on the weight of the loads, they can be transferred in different ways. The light tools and spare parts can be carried by technicians or hoisted by helicopters. The davit crane on the transition piece platform can also typically hoist loads up to 1 ton from the vessel. Moreover, as mentioned earlier, some motion compensated gangways are also capable of transferring spare parts (generally below 1 ton). However, as the weight of the loads increases or the height of the platform goes up, transfer of cargo in the offshore environment can become a difficult issue. In this regard, the motion compensated cranes are introduced to the market. They are usually mounted on SOVs and can position the load on the drop zone even while the vessel is rolling/pitching due to waves and current. Some of them can transfer personnel as well. Although motion compensated cranes are relatively new in the market, it is expected that they will have an increasing role in the future, particularly as individual turbines become larger (hence heavier spare parts). Below, an overview of commercially available and demonstrated motion compensated cranes for components above 1 metric ton are presented. First, the relevant technical characteristics are summarised in Table , then the systems are presented in alphabetical order.

Table 5 Main data of commercially available motion compensated cranes for components above 1 ton.

	Barge Master BM-T40	LIFT2WORK OPTS 24/400	MacGregor	SMST			Uptime by MOTUS		
			Colibri	M	L	XL	M3D 150	M3D 240	M3D 240 / M3D 400
Ability to transfer personnel	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Max. safe working load for cargo	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)	3 ton (at 16m radius: and 500kg at 24 meters)	1 ton; 3 ton; 7 ton; At H_s = 2.5m	3-10 ton	5-20 ton	20-40 ton	Up to 3T@3D 4T-onboard 2fall	Up to 5T@3D 10T-onboard 2fall	Up to 7T@3D 12T-onboard 2fall 20T-onboard, separate winch
Max. Crane Lifting Height [m]	35	22	40	-	-	-	15m@3D 27m - onboard	17m@3D 29m – onboard	17m@3D 29m – onboard
Max. Radius [m]	-	24	35	25	35	35	26m	26m	26m
Compensation DOF	3	6	3	3	3	3	3	3	3
Limiting wave condition Hs [m]	3	2.5	3.5	4.5	4.5	4.5	3	3	3
Wave period limit [s]	4-18	6-10	4	-	-	-	-	-	-
Max. wind speed [m/s]	-	20	24	25	25	25	25	25	25
Foundation footprint	4.8 m, 3.7 m, 3.7 m (triangle)	2.5m by 3.0m	Ø 1.8- Ø3.6 m	Ø 2.2 m (knuckle boom crane)	Ø 2.6 m (knuckle boom crane)	Ø 3.2 m (knuckle boom crane)	Ø 1.75m	Ø2.0	Ø2.25m
Weight [ton]	Barge Master pedestal: 85; HPU: 34; crane: 35	15-25 (with rescue device enables to work 6m below base level)	35-90	45 (with knuckle boom crane)	66 (with knuckle boom crane)	130 (with knuckle boom crane)	25.8	38.8	49.8

Notes
1. Only systems for which technical details were either publicly available or were shared by the developers are included in the table. A blank cell indicates that the data was not made available.
2. The table provides an overview of commercially available and demonstrated motion compensated cranes, but a direct comparison between them should not be made since the numbers included are highly dependent on individual assumptions.
3. The values given for maximum workable sea state (significant wave height, or *Hs*), wind speed and wave period limit are provided by the associated companies and no investigation has been performed by TNO and no warranty is given as to their accuracy. It should be emphasised that the vessel size, hull design, location of the access system on the vessel, maneuvering capacity of the DP system and the captain who is driving the vessel through the motions of the sea, all have a significant impact on the accessibility, which cannot be accurately captured by just one (or a few) environmental parameter(s).

Barge Master BM-T40

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. Currently there are two BM-T40 systems in operation, servicing the Shell/NAM platforms (Oil & Gas) onboard Wagenborg's Kroonborg (since 2014) and Kasteelborg (since 2018). [29].

Figure 33 Barge Master BM-T40 [28].

MacGregor 3-axis motion compensation crane

MacGregor's 3-axis motion compensation crane compensates for the pitch and roll movements of the vessel with the hydraulic crane base (pedestal), and actively compensates the heave motion on the winch of the crane. It can also be connected to a personnel basket to transfer technicians. The system has been used since 2014. However, only the existing systems are available for use, and no new products of this series will be produced.

Figure 34 MacGregor 3-axis motion compensation cranes [30].

MacGregor Colibri

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) will be 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.

Figure 35 Colibri 3D motion compensated crane [31].

SMST 3D motion compensated cranes

SMST offers three sizes of the 3D motion compensated cranes (M, L and XL) [32]. The crane has a modular design which can be new-build and retrofit on the SMST knuckle boom crane of the corresponding size (M, L and XL). Eight systems have been installed on vessels: two M-size with capacity of 1 ton on the vessel *Edda Passat* and *Edda Mistral*; two M-size with capacity of 3 ton on the vessel *Bibby Wavemaster Horizon* and *Esvagt Froude*; 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 36 3D motion compensation crane in operation (Courtesy of SMST).

Uptime by MOTUS 3D motion compensated cranes

Uptime by Motus offers the 3D motion compensated cranes MMC150, MMC240 and MMC400 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 (Z), telescopic derrick (X) and slewing (Y). The robust crane has a low weight, and can be supplied with options such as personnel lift and heavy cargo lift.

Figure 37 Uptime by MOTUS 3D motion compensated crane [33]

4 Access to the hoisting platform

Helicopters can provide access through the hoisting platform on top of the wind turbine nacelle and through the helideck of the substation for wind speeds up to 20 m/s [4]. Because of the safety issues regarding helicopter access, ditching (safe landing on water during emergency) requirements have been established which also dictate a limiting maximum sea state for helicopter transportation. Helicopters can significantly decrease the travelling time compared to CTVs but they are expensive (typically costing 100 – 200 euros per minute, depending on the size of the helicopter) and can only carry a small number of technicians (usually 3 - 6) and very limited weight of small spare parts and tools (usually less than 100 kg). The time that a helicopter can wait in an offshore wind farm while technicians are at work inside a nacelle is very restricted (typically less than 30 minutes), unless they can land temporarily on a fixed landing platform nearby. In general, the helicopters servicing offshore wind farms do not stay in the wind farm. Therefore, helicopters go back to the heliport after they transfer the technicians and come to wind farm again to pick up technicians once the work is finished. This means a transfer by helicopter requires two round-trips, which doubles the costs.

Figure 38 Offshore wind helicopter access [34].

5 Conclusions & future work

This Chapter presents the main conclusions of the publication and provides the scope of future work.

5.1 Conclusions

The primary goal of this work is to provide an overview of the commercially available and prototyped access solutions for offshore wind. The comparative study outlines that currently a wide range of CTVs is mainly used for offshore wind activities, providing access up to sea states of H_s of typically 1.2 to 1.5 m. In addition, several systems that enhance CTVs' performance in terms of accessibility and safety (mostly access gangways) have been developed, but only a limited number of systems are commercially available. In fact, none of these commercially available systems are currently in use on CTVs, except for Mobimar gripper, which is only installed on the vessels that are built by Mobimar. To have an improved accessibility, SWATH vessels are increasingly used, especially for the installation and commissioning of offshore wind farms. Due to the transit speed of the vessels and induced sea-sickness to the technicians onboard, access through CTVs is generally relevant for near-shore wind farms closer than 40 km from shore. With much higher transit speeds, SES can service wind farms further offshore, up to approximately 70 km from shore. However, only a very limited number of SES vessels are currently available and in use for the offshore wind sector. For wind farms far offshore (more than 70 km), offshore accommodation solutions are more suitable.

The current trend of wind farms being built further offshore opens up a larger potential market for SOVs and motion compensated gangways as the access methods, operating typically at sea states of H_s up to 3.0m. However, even for distances from shore of less than 70 km, strategic reasons have already led some service providers and wind farm owners to choose SOVs over CTVs. In recent years, the offshore wind industry has seen a clear rise of SOVs: an increasing number of these vessels have been used for the wind farm installation, commissioning and scheduled (short-term) maintenance campaigns. Moreover, many dedicated offshore wind SOVs with integrated motion compensated gangway are entering the market for the (long-term) daily O&M of offshore wind farms. This has also led to the trend in the motion compensated gangways to become more SOV-focused, with "stepless approach" of transferring technicians and cargo, compatibility with trolley operations, automated landing and digital integration with the SOV.

Still dominating the market, CTVs have seen a trend to become faster and more fuel-efficient. Furthermore, the industry is foreseeing cleaner CTVs with electric, hydrogen or hybrid engines to reduce the CO2 footprint. To fill the gap between CTVs and SOVs, SATV has entered the market. With lower costs than SOVs and also being able to accommodate technicians offshore over nights, it is seen to have large market potential in Asia.

Additionally, motion compensated cranes have started to play a more important role in transfer of cargo, and optionally personnel as well. The trend presents that an increasing number of motion compensated cranes has been installed on SOVs and other W2W vessels, and their market is expected to continue growing in the future as the wind farms are becoming further away and the individual turbines are becoming larger and heavier, resulting in larger and heavier parts. Although an increasing number of motion compensated gangway systems can handle cargo lifting (typically 1-6 tons) as well, dedicated motion compensated cranes still have great advantage of having much larger lifting capacity (up to 10-40 tons). Some large vessels are seen to have both systems installed: one for personnel, and one for cargo, in order to maximise the flexibility and the speed of handling.

Finally, due to the high costs as well as the low passenger and cargo capacity, helicopters are not seen as the main transport method for offshore wind farms. However, helicopter support can be quite beneficial due to the fast response time and high accessibility. Therefore, it is expected that helicopters will be used primarily for emergency transfers, high urgency repairs and more for auxiliary access than for regular transportation.

5.2 Future work

The following activities are planned by TNO:

1. We will continue to follow the development of offshore wind access systems in order to update this report on an annual basis.

2. We are continuously upgrading our wind farm logistics modelling and simulation software. In the future versions of this report, the software may be introduced with new case studies.

We invite readers to contact us and welcome offers of collaboration to update both this annual report and our O&M modelling. Should you be interested to participate and contribute to the development, please contact us by email at windenergy@tno.nl

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