TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 13
Number 1
March 2019
DOI: 10.12716/1001.13.01.18

A Comparison Between DP Offshore Loading Operation on Submerged Turret Loading System STL, Submerged Single Anchor Loading System SAL and Offshore Loading System OLS Considering the Hydro-meteorological Condition Limits for the Safe Ship's Operation Offshore

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ABSTRACT: The purpose and scope of this paper is to describe the characteristics of and make comparisons between DP Offshore loading operation on Submerged Turret Loading system STL, Single Anchor Loading system SAL and Offshore Loading System OLS considering the hydro meteorological condition limits enabling safe ship's operation offshore. These systems (STL, SAL & OLS) are designated to operate with specialized DP shuttle tankers, which are equipped with bow loading system (BLS) and optionally also with bottom submerged loading system STL. All above systems are typically used for short term mooring applications offshore associated with the offloading and/or loading of bulk liquid fuel tankers transporting refined and unrefined products of crude oil or liquefied natural gas LNG.

1 INTRODUCTION

There are a number of different submerged terminals located offshore, outside port limits or in sheltered anchorage areas where larger ships which cannot approach ports or terminals ashore are berthed and the cargo transfer is carried out offshore [1], [3], [7], [8], [10].

In this paper we are going to describe the main characteristics of and make comparisons between the Submerged Turret Loading system STL, Single Anchor Loading system SAL and Offshore Loading System OLS, considering the hydro-meteorological boundary conditions (weather limitations) enabling ships to carry out safe cargo, manoeuvring and DP operation offshore. All mentioned above systems (STL, SAL and OLS) are designated to operate with specialized shuttle tankers (DP class vessels set up for DP class 2 operation), which are equipped with bow loading system (BLS) and optionally also with bottom submerged loading system STL.

All items described in this paper are based on the common requirements covered by the specified oil field offshore operation manuals (e.g. [2], [3], [6]), installation makers operational manuals and ship's operator manuals, which include Teekay Shipping company experience factor [11] collected from the fleet since 1979 and the author's own experience and observation collected on shuttle tanker fleet in offshore industry since 1997.

2 SUBMERGED TURRET LOADING

The Submerged Turret Loading buoy commonly known as STL system incorporates a turret connected to the mooring and the riser. The STL system in basics configuration works as follow: a buoy moored to the seabed is pulled into and secured in a mating cone into the bottom connection STL system on tanker vessel. All STLs are based on standardized mating cone geometry in the vessel (see Figure 1).

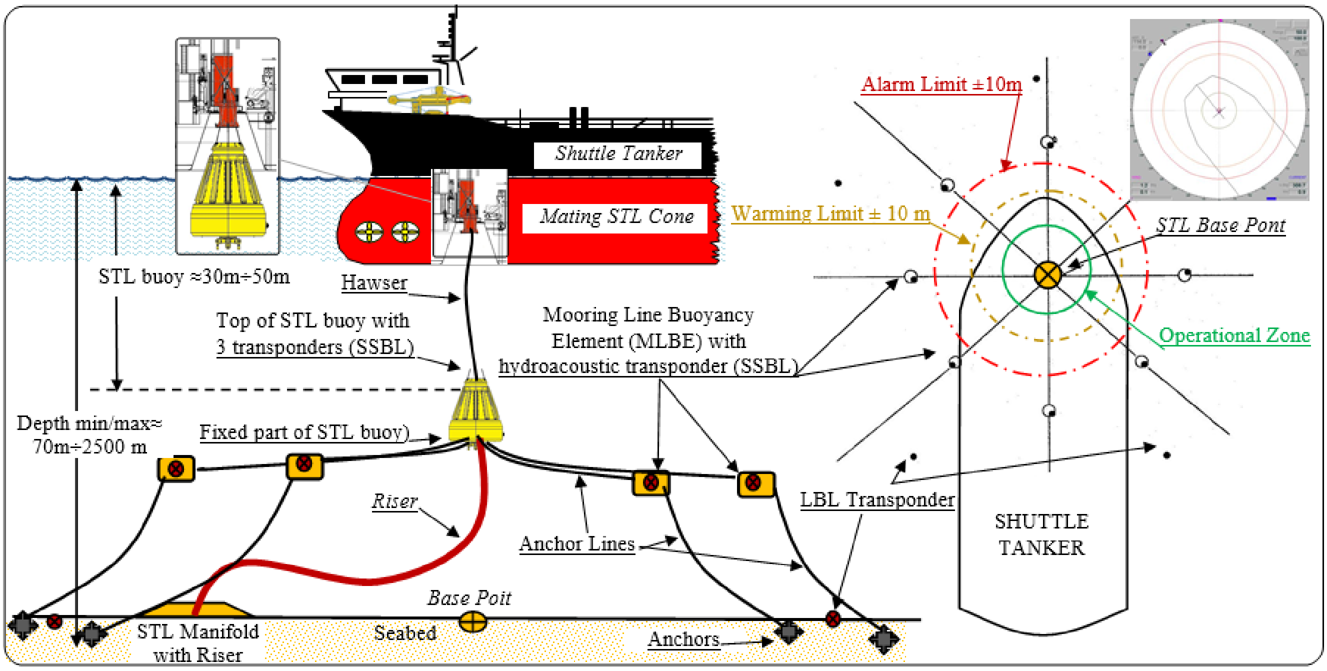

Figure 1. The STL Submerged Turret Loading system in basic configuration with marked safe operational zone, warming limit (±5m) and alarm limit (±10m) setup for DP shuttle tankers based on STL Operational Procedure in Teekay Shipping [6].The world first STL system has been installed at Fulmar oil field on FSO Vinga in 1993 for Shell operator, on depth 85 m, with design life 10 years and design sea waves Hs= 10 m. The first STL system in Direct Shuttle Loading (DSL) configuration has been installed on Heidrun Oil Field offshore Norway in 1994 for Statoil operator, on depth 340 m, with design life 25 years and design waves Hs= 15.5 m. The first offshore LNG Receiving Terminal (LNGRV) Energy Bridge for LNG carriers with regasification plant and STL system connection has been installed on US Gulf Gateway in 2004, 110 nautical miles offshore Louisiana for Excelerate Energy operator, on area with water depth 91 m, design life 20/40 years and design waves Hs= 11.9 m.

Normally on each DP class shuttle tanker officer on the watch, which is navigator and usually also Dynamic Positioning Operator (DPO) when approaching and connecting to STL buoy must use Dynamic Positioning (DP) system setup for DP class 2 operation.

When approaching and connecting to the STL buoy the following DP modes are in use: DP Approach mode is used when ship approaching between 1500m and 5m off the terminal base point (STL buoy position), DP Connect mode and DP Go to Base/Buoy mode is used during connection to and disconnection from the STL buoy and DP Loading mode is used when ship is loading the cargo on STL buoy.

In DP class two operation minimum three position reference systems (PRS) are required to be in use by the DP system on the shuttle tanker and usually there are as follow: one Hydroacoustic Position Reference system (HPR) and two (absolute) Differential Global Navigational Satellite System (DGNSS / DGPS). The HPR system typically consists of Super Short Base-Line (SSBL) and Long-Base-Line (LBL) configuration. Each STL buoy is equipped with a set of HPR transponders. In basic STL configuration e.g. on Heidrun Oil Field we had 5 seabed LBL transponders, 8 Mooring Line Buoyancy Element SSBL transponders and 3 STL buoy SSBL transponders.

Assuming the DP system has been prepared prior to arrival at the field, the following will apply: Between 3000m and 1200 m from the base point (STL position), the pickup line on the shuttle tanker will be lowered trough the mating cone with a sandbag and a floating element. The shuttle tanker will stop and thrust sideways by 0,5 knots (0.25 m/s). The sandbag will be hydrostatically released, and the floating element will rise to the surface. It will be picked up by the crew and made fast on the port side, forward. The vessel will then continue its approach. Inside 500m zone ship's speed must be reduced to 0.6 knots (0.3 m/s) with maximum step forward no more than 50m.

In distance about 300m from selected STL buoy DPO must activate appropriate application on HPR system with software for proper buoy (e.g. STL Heidrun1) and interrogate LBL transponders on seabed. Then DPO must scan Mooring Line Buoyancy Element transponders to check depths of the 8 buoyancy elements. On typical STL installation e.g. on Heidrun oil field there are on depth about 80m to 100m. When scan is finished he must switch system to off. When HPR is stable, DPO must arrange position drop-out, select HPR as reference origin, select DGNSS/DGPS 1 and 2 as PRS secondary systems. Then DPO should continue approaching towards shooting position using DP Approach mode with recommended speed 0,4 knots (0.2 m/s) and maximum step forward no more than 10 m. In distance about 200m from STL base point DPO must stop the vessel in shooting position, pick up the messenger line and while picking up the slack on the STL messenger line resumed approaching towards STL base point.

At distance about 50m from STL base point, DPO should activate STL buoy hydroacoustic transponders by selecting on HPR system option for auto scan. The HPR system usually select the best transponder automatically. When the STL transponder has been calibrated the STL buoy position can be monitored on the assigned view on DP screen. Normally the STL buoy should be detected on the depth approximately 45m ± 5 m. In this point the ship speed setup on DP console should be no more than 0.3 knots (0.15 m/s) and step forward 2 to 5 m. In position at Bow Base distance 5 m DP shuttle tanker must be stopped with intention to check that ship's positioning is stable with sway and heading. When the vessel's DP positioning is stable, DPO should change DP Approach Mode to DP Connect Mode and approach to STL base position using Change position application with DP function Go to Base. When the shuttle tanker is already located at the Base/Buoy position, the STL buoy mooring arrangement is ready to be hoisted into the mating cone. During the hoisting of the STL buoy the depth of the buoy relative to the ships bottom must be monitored on the DP view. In addition, DPO can also use the cameras system on shuttle tanker to monitor the last phase of the hoisting. When the top of the STL buoy is getting near to the ship's bottom, the signal from the STL transponder will no longer be available, and it should be switched off. When the STL buoy is locked the 'STL Buoy in Position' message is displayed on the DP console. In this point DPO should change DP Connect mode to DP Loading Mode.

When DP shuttle tanker is operating in DP Loading Mode the predefined alarm limits on DP console are active. However, DPO can also define additional fore and aft position alarms limits with e.g. deviation ±5 m for warmings and ±10 m for alarm indication. When DP Loading Mode is pressed, the status lamps for Loading, Surge, Sway and Yaw buttons are lit. The set point for heading and position is set to the current estimated vessel heading and position. The vessels rotation point (CR) is the position of the mating cone.

Field-specific limits for STL connection and loading are programmed into the dedicated DP software (buoy selection). Specific limits and configuration differ from one loading installation to another. For Kongsberg-supplied DP systems, the following alarm wording are used:

Warning ESD1 (Emergency Shut Down Class 1) – 'Distance to base too long'. On Shuttle tanker stop loading procedure are to be activated if this limit is exceeded.

Alarm ESD2 - 'Distance to base critically long'. On Shuttle tanker stop loading & emergency disconnection procedure are to be activated if this limit is exceeded. However, it must be also noted, that according to specific oil field procedure ESD2 alarms with disconnection procedure are not always applicable e.g. on old STL installation on Heidrun Oil Field in North Sea.

While Tanker is in DP Loading Mode, the DP system takes account of the restoring forces of the STL mooring system. The damping and restoring forces of the STL mooring system depend on the offset from the base position and the depth of the buoy. DPO can use the STL Mean Offset function to keep the vessel at a specified mean distance from the base position using only surge thrust towards the base position. To activate the Mean Offset function, DPO must select axis control by pressing on DP console one of the axis button and deselect surge. Optionally DPO can press the change position button on DP console, select a set point radius and check the STL Mean Offset box and Apply. Normally the DP system will maintain a mean distance from the STL base point. It takes the restoring forces from the STL mooring system into account and calculate, over time, a constant amount of propeller thrust needed to maintain the offset position. If the DPO reactivates all axis again, the DP will take present position and heading as new set point and will maintain the offset position. If the DPO wishes to maintain a position closer to the base point, he can do this by pressing the change position button and select Go to Base and Apply.

However, in good weather conditions it is most common for shuttle tanker to stay in STL Loading Mode with no thruster active and only DGPS as reference system. The vessel will rotate freely around the STL turret. When loading is completed, the vessel will disconnect from the STL more or less in the opposite sequence of how the vessel connects to the buoy. The DPO will select on DP Connect mode and Go to Base application. The STL system will be disconnected and lowered to its normal depth. Than DP system must be setup to DP Approach mode, and the vessel will move astern while slacking away on the messenger line until the marker buoy is in the water. The STL buoy drops clear of the vessel, and floats in an equilibrium position approximately 30 to 50 meters below sea level.

In normal circumstances the time for connection from the position, when vessel already approach to STL base point, usually takes about 10 to 15 minutes. Disconnection usually takes only a couple of minutes and can be performed in any weather condition. Usually ship's owner and the field operator have defined their own individual weather limits for connection, loading and disconnection operations. The strictest (lowest) limits are to prevail.

According to field operator and APL manufacturer for most of the STL systems [1], connection can be done in sea states between 5 and 7 m Hs (Significant Wave Height). Weather independent offshore loading. Disconnect regardless of weather conditions in any sea state. On another hand, e.g. Teekay's limits are as follow: for STL connection with DP System Mode, the maximum significant wave height (Hs)= 4.5 m and the period of maximum wave height (Tmax)= 15 seconds; for STL loading and normal disconnection with DP System Mode, the maximum significant wave height (Hs)= 10.0 m.

The STL system also allows for schedule decoupling between the offshore and the shipyard work. STL, mooring and riser can be completed independently from the OLT or FSO. The STL system is installed on site prior to the FSO or OLT arrival at the field. Upon arrival, the vessel hooks up onto the STL on its own. Unplanned repair, upgrading, inspections and replacement of the FSO, as well as abandonment of the field, is simplified by the disconnect feature of the buoy based STL system. The STL system can be designed for disconnect service (OLT, DP Shuttles, LNGRV) or for permanent mooring throughout the field life (FSO/FPSO).

According to Advanced Production and Loading APL National Oilwell Varco website [1] the Submerged Turret Loading system STL represents the state-of-the-art technology within all offshore loading industry and is commonly recognized as 'the best and most innovative solutions combined with life-cycle commitment'. The STL technology offers a flexible, safe and cost-effective solution for Oil Loading Tankers (OLT), LNG tankers and Floating Storage and Offloading units (FSO). The STL systems in service cover a wide range of application from the harsh North Sea environment to cyclone prone areas such as China or Australia, mooring caters for sea as high as 19 m Hs (Significant Wave Height), water depth up to 2500 m, vessel sizes up to ULCCs, throughput production up to 600 000 BOPD (barrels of Oil Per Day). The STL is also widely used to moor LNG carriers either Floating Storage Regasification Units (FSRUs) or high-pressure LNG Re-Gas Vessels (LNG RV). The STL technology, as it was described above, has also a high availability in harsh environments and is well proven since 1993 with number of successful STL connection, loading and disconnections offshore.

In real life e.g. in November and December 2001, the Haltenbanken area off mid Norway with dual STL installation on Heidrun oil field experience a 100-year storm with reported maximum wave heights over 25 m and significant wave height over 16 m. That time the Heidrun field didn't have infield oil storage and production was therefore dependent on a tanker moored to one of the two STL buoys. That time two DP shuttle tankers Navion Norvegia and Navion Europa were, based on the weather forecast [1], connected to two STL buoys and remained connected receiving oil through the storm. As of June 2011, total of 1131 loads via STL system corresponding to 962 Million barrels of oil have been delivered from Heidrun field via STL system on DP shuttle tankers to ashore. Overall offtake regularity on STL Heidrun, also taking whether downtime into consideration has been over 99.9%. Another example for STL system operation in extreme storm has been recorded on FSO STL mooring system on Aasgard C oil field on North Sea in January 10-11, 2006, which experience storm with significant wave 16.8 m, maximum wave height 29.0 m, wind 95 knots (equivalent to hurricane Category 2 wind and hurricane category 5 wave).

Mentioned before Energy Bridge LNGRV installation is also designated for 100-year Gulf of Mexico hurricane both with vessel connected and disconnected. In August 2005, Gulf Gateway performance e.g. hurricane Katrina (category 5 storm) when Energy Bridge LNGRV Excellence continues operations with 5 to 6-meter sea states and 50 knots winds until discharge operation has been successfully completed with no interruptions due to weather.

The STL systems has been verified also in ice environments. Model tests have documented survival of a vessel moored in 1.6 m level ice with drift speed of 0.75 m/s. It has been also noted, that icebergs and ice ridges in arctic environments usually are better addressed with the quick disconnect features provided e.g. by the STL or SAL system.

3 SINGLE ANCHOR LOADING

The SAL Single Anchor Loading system is offshore loading system introduced in the late 1990's, that serves as a single mooring point via hawser to the underwater strong base anchor as well as an interconnection for tankers loading or offloading gas or liquid products [1], [2].

The SAL system was developed as low-cost alternative to the STL system for use in the situation where traditional CALM buoys cannot be used. As the SAL is subsea the risk of collision between the tanker and traditional CALM or SPM buoy is eliminated. On SAL system the vessel always takes the most favourable position in relation to the combination of wind, current and wave and is free to align itself with the prevailing environmental forces at the time.

The central elements of the SAL system are a mooring and a fluid swivel with a single mooring line (hawser) and a flexible riser for fluid transfer attached, anchored at the sea bed by the use of a single anchor. The anchor also functions as the pipeline end manifold (PLEM) for the seabed export flow line. A tanker is hooked up to the system by pulling the mooring line and the riser together from the seabed and up to the bow of the vessel. Here the mooring line is secured and the riser is connected to the vessel. Moored to the SAL system, a tanker can freely weathervane. Disconnection is performed by lowering the mooring line and the riser down to the seabed.

Nowadays there are a several types of SAL systems in use. The SAL flexible riser (offloading hose) can either be designated for connection to a standard shuttle tanker bow loading system BLS or to the typical amidships manifold of a standard trading tanker. The SAL can be equipped with clump weight system (e.g. Hanze SAL installed in 2001, Solan SAL installed in 2015) or underwater buoyancy systems (e.g. Banff SAL or South Arne SAL installed in 1998). Typical SAL system is usually equipped with strong mooring hawser with chafing chain designated for tanker with chain stopper located forward for single point mooring SPM system on board the tanker vessel (e.g. installation of South Arne SAL with mooring hawser capability limited to 450 tons on weak link). However, there are also SAL installation without upper mooring system, which are in configuration typical for traditional offshore loading system OLS, which are designated only for full DP shuttle tankers equipped with bow loading system BLS. Nowadays most of the SAL systems are typically used offshore for short term mooring applications recommended for DP shuttle tankers setup for DP class 2 operation, equipped with BLS system.

In general approach the typical SAL terminal is quite easy to install. It has been noted that new SAL terminal can be installed on oil field offshore just within few days up to few weeks period. It has been also noted that the old SAL systems can be easy reused and/or upgraded (e.g. Ardmore twin SAL systems have been re-used for Kittywake SAL installation in 2005 and Don SAL installation in 2008, Siri SAL buoyancy system has been upgraded from buoyancy SAL system to clump weight SAL system in 2009).

SAL system has been also successfully tested in arctic zone. Artic SAL Varandey system, which has been installed on Pechora Sea in Russia on Summer in 2002 on water depth 12 m for Varandey Neftegaz and Murmansk Shipping Company with dedicated tankers mt Saratov and mt Usinsk (20000 DWT, Class LU5, DNV-GL 1A Polar) is designed to work with temperature up to -40°C, summer loading Hs= 3 m, 20 m/s wind and tidal current 1.6 knot. The worst conditions encountered so far on this SAL installation during loading include 150 cm ice layer and temperature -32°C. Specially designed hose (16’’ID) with rugged design for operation through ice, developed by ITR for APL in cooperation with Murmansk Shipping Company, Arctic and Antarctic Research Institute, St. Petersburg with DNV-GL (3rd party verification) are designed to work with oil temperature to -20°C, ambient temperature to -40°C and hose designed for mooring loads up to 200 t.

SAL system with clump weight comprises the following main sub-systems: anchor assembly, mooring system and riser (offloading) system. Mooring system contains lower polyester mooring segment, mid line clump weight with integrated steel spool piece and upper mooring (hawser) with chafing chain and pick-up assembly (e.g. SAL Solan, see Figure 2). In buoyancy SAL systems (e.g. South Arne SAL - see Figure 3) the mooring system is made up of the following components: lower wire segment, mooring line buoyancy element, lower rope segment, additional buoyancy element, upper rope segment, chafing chain and pick-up assembly.

The lower wire segment connects the mooring line buoyancy element to the SAL anchor top structure. The purpose of the mooring line buoyancy element is same as clump weight system to serve as a spring function in the SAL mooring system, serve as support for the loading hose and assemble mooring lines and loading hose at a common point. The mooring line buoyancy element is situated between the lower wire rope segment and the lower rope segment, and consists of a cylindrical steel structure, which is connected to a connecting rod. The rod is an integrated part of the mooring line carrying the mooring line tension that is no mooring forces are transferred through the hull of the buoyancy element. In light of SAL mooring system handling requirements during operation, fibre ropes were chosen instead of wire ropes. Two fibre rope segments, a lower fibre rope segment and an upper fibre rope segment connect the mooring line buoyancy element and the chafing chain, via the additional buoyancy element. Both sections of rope are manufactured from Polyester. The additional buoyancy element is designed to avoid contact between the fibre rope segments and the seabed, and to reduce the stiffness of the mooring system in disconnected condition.

The SAL installation is fixed by SAL anchor. The ship is made fast to the SAL with the help of a single chain with hawser which is secured on board to the bow stopper. The vessel always takes the most favourable position in relation to the combination of wind, current and wave and is free to align itself with the prevailing environmental forces at the time. As the vessel in its stationary state is always positioned head-on into the wind’s/current’s direction, the total force is less than would be experienced by a vessel on a fixed mooring which is not always head-on into the prevailing conditions. The basic principle of SAL system is to keep the position of the vessel with respect to the SAL base steady and at the same time allowing vessels to swing to wind and sea. This operation is typical for shuttle tanker on DP weather vane mode.

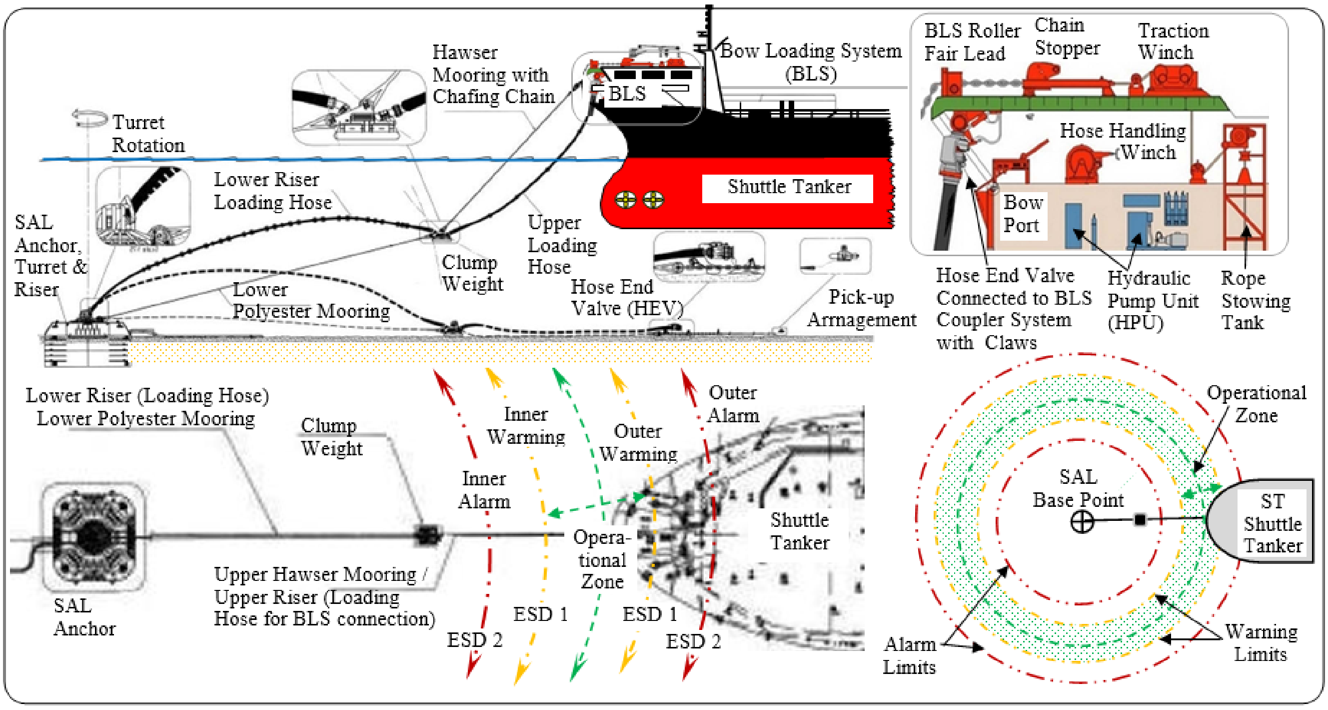

Figure 2. The Single Anchor Loading (SAL) system in Clump Weight configuration with safe operational zone, inner and outer warmings and alarm limits setup for ESD1 (Stop loading procedure) and ESD2 (Stop loading + disconnection procedure) for DP shuttle tankers with Bow Loading System (BLS) based on SAL Clump Weight Operational Procedure [1], [6].

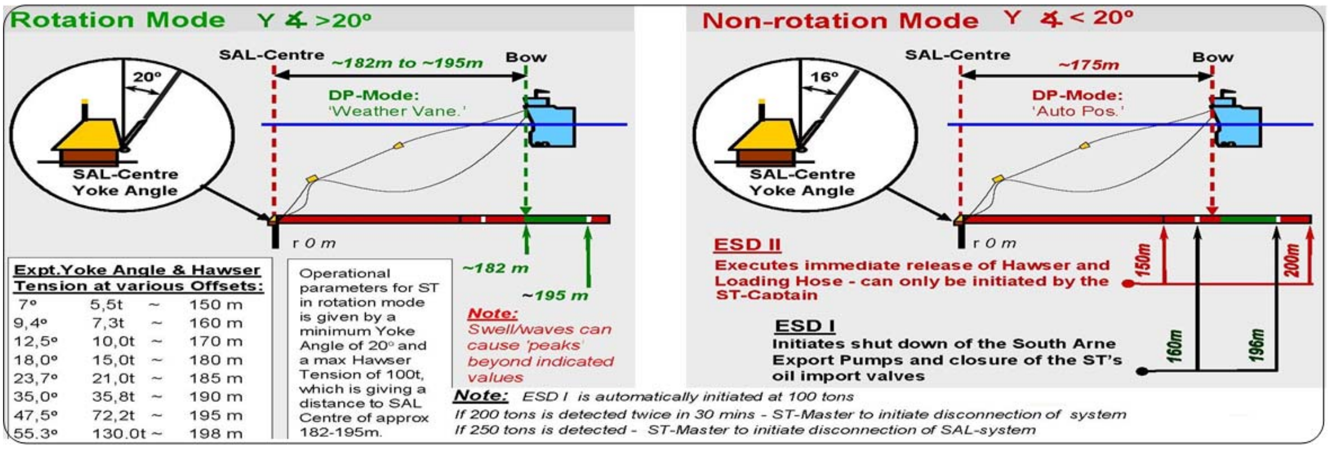

Figure 3. The South Arne SAL buoyancy system with operation parameters for DP shuttle tankers based on HESS Oil Export and SAL System Operating Procedure DOM-SA-P-001B. [6]

SAL systems are usually located in water depths between 30 to 100 meters and are connected to a shore storage facility (tank farm) or to offshore production platforms by means of a submarine pipeline. Nowadays most of the SAL systems are designated for DP shuttle tankers with BLS system. SAL configuration can accommodate the largest vessels, including VLCCs.

Usually ship's owner and the field operator have defined their own individual weather limits for SAL connection, loading and disconnection. The strictest (lowest) limits are to prevail. Teekay's limits are e.g. as follow: For SAL connection with DP System Mode, the maximum significant wave height (Hs)= 4.5 m and the period of maximum wave height (Tmax)= 15 seconds. For SAL loading and normal SAL disconnection with DP System Mode, the maximum significant wave height (Hs)= 5.5 m and the period of maximum wave height (Tmax)= 15 seconds.

The above values are normative and must be considered in connection with current weather conditions and whether conditions are improving, stabilizing or worsening. Approach, loading and discontinuation of these activities are always subject to the Master's final approval.

According to oil field procedure [3], [6] and APL SAL manufacturer website [1], [2] DP shuttle tanker can moor to SAL system with significant sea waves up to 4.5 m (maximum wave heights 8.1 m) and stay connected to SAL when loading with significant sea waves up to 5.5 m (maximum wave heights 9.5 m) and disconnect in seas as high as 7.0 m [1]. In addition, on some oil field [6] vessel has to leave SAL installation when winds exceed 60 knots and waves are higher than 5.5 m. In addition, there is a limited sector (±5°) for positioning when picking up the line from the bottom.

On DP shuttle tankers two different loading modes, rotation and non-rotation modes may be used for loading on SAL systems (see figure 3). Non-rotation mode (Auto Position) is normally used when weather conditions allow it, to reduce strain on the loading system. Rotation mode (Weather Vane) is normally used when weather conditions are above winds of Beaufort force 4 and/or sea state 2 or above.

Hawser tension limits for SAL are normally higher than other systems for offshore loading with shut down (green line failure) on 200 t. Restricted zones are defined where other installations are placed nearby and when there is a risk that the vessel, in an emergency, may drift towards other offshore installations.

Approach to the SAL can be from any direction (from a mooring perspective). If needed the SAL system can be rotated and laid down in an optimal heading by supporting tug prior to pick-up and connection by approaching tanker. However, if supporting tug is not available on the field shuttle tanker can use another procedure and using DP mode 'circle around the buoy' approach to installation offshore without tug assistance (e.g. procedures implemented on Draugen oil field near FSL installation). This DP software give us possibility to approach BLS to fixed position of submerged hose, keeping always on shuttle tanker optimal heading against wind, waves and current and recommended distance to submerged buoy (and/or submerged hose-end-valve with pick up arrangement), pick up the hose from the bottom, safely rotate the ship around the buoy keeping optimal heading and distance to submerged buoy (using 'circle around the buoy' DP software) and when the buoy, offloading hose and shuttle tanker heading are on same line against wind, waves and current, approach closer, connect the hose and/or hawser and if all is OK in good order, complete connection and set up DP to Weather Vane mode.

Mooring typically takes 30 min to 1 hour (once vessel has arrived at SAL installation and connect mooring pick up assembly). Connection and disconnecting from mooring on DP shuttle tanker does not need tug assistance, although tugs may be required for connection depending on the local site condition and availability of space for vessel manoeuvring and SAL rotation requirements. Hose connection to BLS usually takes about 10 to 15 minutes. Typically, vessels are only able to offload a single product at a time. Disconnecting from mooring on DP shuttle tanker typically takes about 20 to 30 min.

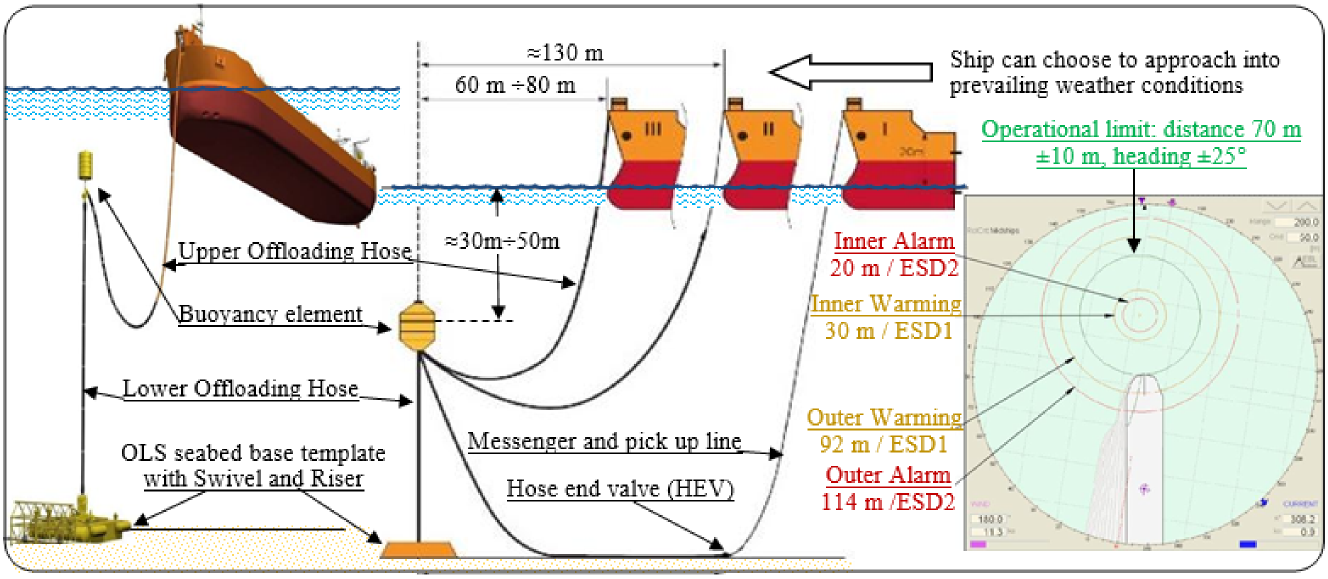

Figure 4. The Offshore Loading System OLS sometimes denoted also as UK-OLS, which stands for Ugland-Kongsberg OLS system with clearly marked operational zone preferred loading distance 70m ± 10 m, inner and outer warmings and alarm limits for ESD1 and ESD2 procedure setup for DP shuttle tankers with Bow Loading System BLS based on OLS Operational Procedure [1], [6].

4 OFFSHORE LOADING SYSTEM

The OLS is short for submerged Offshore Loading System without hawser and only hose connected to the ship's BLS system. The full name of OLS is sometimes denoted UK-OLS, which stands for Ugland-Kongsberg Offshore Loading System. In May 2018 some OLS installations has been operating on North Sea in Norwegian and UK sector e.g. at the Statfjord field, A and B, at the Gullfaks field 1 and 2, Harding field and on Atlantic Ocean e.g. in Canadian sector on Hibernia and Hebron Oil Field, where we have SAL system in OLS configuration with only submerged hose connected without hawser. The OLS systems usually have been installed offshore in sea area with depth from 80 to 150 m. However, there is also a similar system to OLS configuration designated for deeper water known as Framo Submerged Loading system FSL (e.g. FSL Generelt on Draugen oil field operated by Norske Shell A.S. with a sea depth of 250 m).

The OLS in basic configuration consists of a seabed base template, buoyancy element 'Coflexip' hose, swivel, hose end valve, messenger and pick up line. The OLS system (see figure 4) is hawser less operation, only with hose connected to the BLS system on DP shuttle tanker setup for DP class 2 operation.

When a DP Shuttle Tanker (ST) arrive at the field, the master will evaluate the weather conditions to decide on a direction for approach to the OLS system. This will be a direction typically into the wind, taking into account the direction of the waves and current if known. The master will then instruct the support tugboat/standby vessel (SBV) to rotate the loading hose into the opposite direction of the intended direction of approach. The SBV vessel will pick up the loading hose and rotate it in the direction indicated by the master of the shuttle tanker. The SBV vessel will then move to a position about 250 m from the OLS base and wait for the shuttle tanker to approach. The passing of the messenger line from the SBV to the ST bow usually take place on the port side. During connection, loading and disconnection 3 reference systems shall be used for DP simultaneously: DGNSS1/DGPS1, DGNSS2/DGPS2 and HPR or Artemis. DGNSS1/DGPS1 or DGNSS2/DGPS2 (Absolute Positioning) shall be selected as reference origin. If HPR is not activated on the DP, it shall be available at any time as a visual reference.

From the 10 Nm Zone, where end of sea passage (EOSP) is usually recorded, the vessel must gradually reduce speed, and prepare to stop at 900 m. From 900 m the vessel must use the DP system to move into connection and loading position in accordance with the established step-by-step procedure for the specific oil field. DPO must prepare the DP according to the DP checklist handed out. All checks must be completed using the oil field procedure. DP system must be prepared and proper loading buoy from the DP Offload menu must be selected. Since OLS operations does not involve a hawser, DPO must be sure that the hawser sensor on DP software is not activated. DPO should verify all other sensors including gyros, wind sensors, VRS/MRU (for pitch and roll indication for PRS system), draft sensors and etc. When all DP tests are completed, DPO should change ship's thrusters' main control to DP Approach mode or DP Auto Pos mode. Normally when approaching to any installation offshore from 900 m to 500 m DPO should use the maximum step forward up to 100 m and maximum speed setup to 1,2 knots (0.6 m/s). Close to 500 m zone DPO should reduce the ship's speed and ask OIM (Offshore Installation Manager) for permission to enter 500m zone and if needed prepare to stop the ship at 500m bow base distance. Some fields require on DP Position Dropout and let the vessel settle down for a couple of minutes at 500 m zone with intention to verify DP model including selection and quality of reference systems. In this point DPO must calibrate DGNSS1/DGPS1 as PRS origin, add DGNSS2/DGPS 2 as a secondary PRS system and select remaining PRS e.g. HPR and/or Artemis. DPO must observe DP model stability for minimum 5 minutes and verify vessels ability to keep position. If DP Standby Mode was selected than he must rebuild new DP model for minimum 20 minutes. If DP model is stable than DPO can go ahead to the next step of approaching procedure and if not than he must stop the vessel, report this to OIM and/or OLS control room and abort operation.

On next step DPO must select DP Approach or DP Auto Pos mode on the DP console. He must ensure that the vessel is outside any restricted zones and that the vessels bow is within ±15° compared to the agreed direction of the hose laid down on the sea-bed. Continue to shooting position at approximately 250 m bow base. Maximum speed 0.6 knots (0.3 m/s). Maximum set point radius must be changed to 50 m. DPO must monitor thruster response and adjust speed in order to stop tanker completely at 250 m base distance. DP shuttle tanker should stop at shooting position approximately in 250 m bow-base (BB) distance. The SBV to take position approximately 50 m from the ST port bow quarter. When the messenger line has been received, DPO should continue approaching towards 150 m BB distance with speed 0, 6 knots and max 50 m steps while picking up the slack on the messenger line. DPO must be sure that the bow is inside ±15° limit to the hose. From 150 m BB ST should move slowly towards 130 m BB distance while picking up slack on the messenger line. Max steps to be 10 m and speed to be 0, 4 knots. ST must stop at BB 130 m.

At 130 m, ST must pull the messenger line until the 60 m mark reach the bow fairlead, change the speed to 0,4 knots and max set points steps 10 m. When in loading position (70 m ± 5 m), DPO should activate the fore and aft alarms limits, e.g. with ± 5 m values. Then select DP Weather Vane mode and continue to heave on the messenger line until connection of the loading hose can be made. When hose end is in BLS position and the coupler claws are closed, the DP will receive a Hose Connect signal, and Position Activated Shut Down (PASD 1) function becomes active. When the hose is connected, and all tests are completed, DPO should call the offshore installation and inform offshore terminal that the vessel is ready to receive cargo.

When loading completed, follow procedure, disconnect and proceed to discharge port.

On each individual OLS installation field-specific limits for OLS connection and loading are programmed into the dedicated DP software (buoy selection). Specific limits and configuration differ from one loading installation to another. For Kongsberg-supplied DP systems, the following alarm wording are used e.g. on Statfjord A OLS installation (see figure 4):

- Operator selected setpoint radius with preferred loading distance 70 m ± 10 m;
- Inner Warning limit 30 m (distance to base too short) and Outer Warming limit 92 m (distance to base too long). Action: ESD1 with stop loading procedure is to be activated if these limits are exceeded.
- Inner Alarm limit 20 m (distance to base critically short) and Outer Alarm Limit 114 m (distance to base critically long). Action: ESD2 with stop loading & disconnection procedure is to be activated if these limits are exceeded.
- Alarm ESD1 with bow base heading deviation too high and PASD if heading deviation from basepoint exceeds ±25°.
- Alarm ESD2 with bow base heading deviation critically high and PASD with disconnection procedure if heading deviation from basepoint exceeds ±30°.

Ships usually can approach and connect to OLS with winds up to 40 knots and significant sea waves (Hs) up to 4.5 m, max. sea waves (HSmax) up to 8.5 m, sea waves period (Tmax)= 15 sec. Vessel has to leave OLS installation when winds exceed 60 knots and/or significant sea waves (Hs) are higher than 5.5 m (max. sea waves heights (HSmax) up to 9.5 m), period (Tmax)= 15 sec.

5 COMPARISON SUMMARY

Summing up the above, it can be assumed that in the offshore sector, the expensive offshore loading systems will be replaced by the cheaper and equally effective solutions. The author also believes that the traditional single anchor loading (SAL) systems with the Hawser mooring system will be replaced by the modified SAL systems in the OLS configuration (without the Hawser system attached).

Expensive submerged turret loading (STL) systems will continue to be found in common use, but only on the FSO-FPSO storage and production units and not on traditional shuttle tankers.

Traditional OLS systems will be replaced by a direct loading system at the DP shuttle tankers in the so-called DSL (Direct Shuttle Loading) configured without the support Hawser mooring system.

A summary comparison between DP offshore loading operation on the submerged turret loading system STL, single anchor loading system SAL and offshore loading system OLS considering the hydro meteorological condition limits enabling safe ship's operation offshore has been presented in the following table:

Table 1. Comparisons between DP Offshore loading operation on Submerged Turret Loading system STL, Single Anchor Loading system SAL and Offshore Loading System OLS considering the hydro meteorological condition limits enabling safe ship's operation offshore. Source: Author's own researches.

No	Criteria	STL	SAL	OLS
1.	Vessel size / type	Vessel sizes unlimited / DP class 2 shuttle tanker (VLCC) with Submerged Turret Loading system (STL)	Vessel sizes unlimited/tanker (up to VLCC) with Bow Loading System (BLS) – preferable DP class 2 shuttle tanker	Vessel sizes unlimited / DP class 2 shuttle tanker (VLCC) with Bow Loading System (BLS)

2.	Operating water depth	For DSL from 70 to 350 m, for FSO/FPSO up to 2500 m depth	From 12 m dept (shallow water) up to 120 m water depth	Usually from 80 m to 150 m depth. In FSL configuration up to 250 m water depth.
3.	Approach	Can approach from any position – and therefore can choose to approach into prevailing weather conditions		
4.	Mooring method	Integrated submerged turret with single point mooring system between STL buoy and mating STL cone installed on tanker, where STL buoy usually is anchored by 8 to 16 submerged mooring/anchor lines	Single point mooring system using one hawser with chafing chain connected between submerged SAL anchor and chain stopper located on tanker vessels near Bow Loading System BLS. In addition, there is a limited sector (±5°) for positioning when picking up the mooring line from the bottom.	No mooring system. OSL is submerged offshore loading system without mooring system (without hawser and mooring line). In addition, there is a limited sector (±15°) for positioning when picking up the hose handling line from the bottom.
5.	Mooring time once vessel has arrived offshore installation and connect mooring pick up assembly	Mooring typically takes 30 min to 1 hour depending on the weather condition	Mooring typically takes 30 min to 1 hour depending on the weather condition	Mooring typically takes 30 min to 1 hour depending on the weather condition
6.	Offshore Loading method	Submerged turret STL with integrated loading and mooring system	Loading by integrated Bow Loading System BLS (typical for DP class shuttle tankers). Optionally side connection for conventional tankers	Loading only by integrated Bow Loading System BLS installed on DP class shuttle tankers
7.	Hose connection time (after arriving at mooring position)	STL is integrated loading and mooring system. Connection from the position when vessel already approach to STL base point, usually takes about 10 to 15 minutes.	Hose connection from the position when vessel already moored to SAL system usually takes about 10 to 15 min for BLS system on DP shuttle tankers and up to one hour for side connection on conventional tankers.	BLS hose connection from the position when DP shuttle tanker already approach to OLS base point usually takes about 10 to 15 min. Vessel is not moored and must be in dynamic positioning DP mode (set up as DP class 2) in W.
8.	DP mode during offshore loading operation	It is most common for shuttle tanker to stay in STL Loading Mode with no thruster active and only DGPS as reference system.	On DP shuttle tankers rotation and non-rotation modes may be used for loading on SAL. Non-rotation mode (Auto Position) is normally used when weather conditions allow it, to reduce strain on the loading system. Rotation mode (Weather Vane) is normally used when weather conditions are above winds of Beaufort force 4 and/or sea state 2 or above. Hawser tension limits for SAL with shut down (green line failure) is usually set up on 200 t.	DP Weather Vane mode. When hose end is in BLS position and the coupler claws are closed, the DP will receive a Hose Connect signal, and Position Activated Shut Down (PASD 1) function becomes active.
9.	Time for hose disconnection	STL disconnection usually takes only couple of minutes and can be performed in any weather condition.	Hose disconnection from BLS system usually take couple of minutes, on side connection from 40 min up to 1 hour. During hose disconnection vessel is still moored to SAL.	Typically, about 10 min
9.	Offloading time	Function of cargo pumps capacity, line size and distance. Loading time for typical VLCC shuttle tanker up to 24 hours.		
10.	Time for mooring Disconnection	Typically: 15 to 20 min	Typically: 20 min to 30 min.	Typically: 15 min to 20 min.
11.	Mooring conditions and operational limits for DP shuttle tankers	According to manufacturer STL connection can be done in sea states between 5 and 7 m Hs (significant sea wave height). Weather independent offshore loading. Disconnect regardless of weather conditions in any sea state. Teekay's limits for STL connection with DP mode: Hs= 4.5 m, period (Tmax)= 15 seconds; for STL loading & normal disconnection with DP Mode: Hs= 10.0 m.	Connection: significant sea waves (Hs) up to 4.5 m, max. sea waves (HSmax) up to 8.5 m, Period (Tmax)= 15 sec. Loading: significant sea waves (Hs) up to 5.5 m (max. sea waves heights (HSmax) up to 9.5 m). Period (Tmax)= 15 sec. In addition, on some oil field [6] vessel has to leave SAL and/or OLS installation when winds exceed 60 knots and waves are higher than 5.5 m.	

12.	Operational limit for conventional tanker	N/A. System designated only for DP shuttle tankers (set up as DP class 2) equipped with BLS system	Generally, SAL system is designated for DP shuttle tankers with BLS system. However, optionally there is also possibility for conventional taker to moor to SAL with tug assistance with side hose connection with winds up to 30 knots and head waves of 2.0 m to 2.5 m.	N/A. System designated only for DP shuttle tankers (set up as DP class 2) equipped with BLS system
13.	Offloading steps	Approach and moor to STL system with integrated mooring and loading system, load cargo through STL, disconnect STL, steams away to discharging port	Approach and moor to SAL by single point mooring system (hawser with chafing chain), connect hose, load cargo through BLS (optionally by side manifold on conventional tankers), disconnect hose, disconnect mooring SPM hawser, steams away to discharging port	Approach to OLS and connect offloading hose to BLS system, load cargo through BLS, disconnect hose, steams away to discharging port
14	Tug assistance	Not required. DP shuttle tanker normally can operate without tug assistance.	For conventional tankers tug required full time during mooring and disconnection and to assist with weathervane movements.	Not required. DP shuttle tanker normally can operate without tug assistance.
15.	Under Keel Clearance	Function of the vessel, offshore terminal installation and hydro-meteorological conditions		
16.	Risk of collision	As the STL, SAL and OLS are subsea the risk of collision between the tanker and traditional CALM / SPM buoy is eliminated.		
17.	Weathervane around the buoy	The vessel always takes the most favourable position in relation to the combination of wind, current and wave and is free to align itself with the prevailing environmental forces at the time.		
18.	Night operations	Possible limitation on night time mooring depending on local operational, safety and environmental procedures. In normal circumstances DP shuttle tanker can moor, connect and disconnect from moorings 24 h a day.		
22.	Track record	The world first STL system has been installed at Fulmar oil field on FSO Vinga in 1993 on depth 85 m and design sea waves Hs= 10 m. The first STL system in Direct Shuttle Loading (DSL) configuration has been installed on Heidrun Oil Field offshore Norway in 1994 on depth 340 m with design life 25 years and design waves Hs= 15.5 m. The first offshore LNG Receiving Terminal (LNGRV) Energy Bridge for LNG carriers with regasification plant and STL system connection has been installed on US Gulf Gateway in 2004 offshore Louisiana on area with water depth 91 m, design life 20/40 years and design waves Hs= 11.9 m.	Since introduced in the late 1990's SAL systems have been successfully installed around the world. The SAL flexible riser (offloading hose) can either be designated for connection to a standard shuttle tanker bow loading system BLS or to the typical amidships manifold of a standard trading tanker. The SAL can be equipped with clump weight system (e.g. Hanze SAL installed in 2001, Solan SAL installed in 2015) or underwater buoyancy systems (e.g. Banff SAL or South Arne SAL installed in 1998). SAL system has been also successfully tested in arctic zone: e.g. Artic SAL Varandey system installed on Pechora Sea in Russia on Summer in 2002 on water depth 12 m, designed to work with temperature up to -40°C, summer loading Hs= 3 m, 20 m/s wind and tidal current 1.6 knot.	Since introduced in the late 1990's OLS systems have been successfully installed around the world. In May 2018 some OLS installations have been operating on North Sea in Norwegian and UK sector e.g. at the Statfjord field, A and B, at the Gullfaks field 1 and 2, Harding field and on Atlantic Ocean e.g. in Canadian sector on Hibernia and Hebron Oil Field, where we have SAL system in OLS configuration with only submerged hose connected without hawser installed offshore in sea area with depth for from 80 to 150 m. There is also a similar system with OLS configuration designated deeper water known as Framo Submerged Loading system FSL on Draugen oil field with a sea depth of 250 m.
23.	Cost	A STL system for the same application is in the MUSD 25-30 range, for the subsea part of this system (assuming that to use tankers with the shipboard system already installed). (Data from May 2018 as per [1])	SAL was developed as low-cost alternative to the STL. Typical cost for the SAL system is in the MUSD 12-15 range. (Data from May 2018 as per [1])	OLS was developed as low-cost alternative to the SAL system designated for DP shuttle tankers with BLS system. Typical cost for the OLS system is in the MUSD 8-12 range. (Data from May 2018 as per [1])
24.	Suppliers	Proprietary technology and limited suppliers. Complex maintenance. Hoses damage more due to abrasion from storage on seabed		

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